NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY POLITEHNICA BUCHAREST

Doctoral School of Biotechnical Systems Engineering

PhD THESIS

SUMMARY

RESEARCH ON THE DEVELOPMENT OF COMPUTATIONAL ALGORITHMS FOR DETERMINING THE OPTIMAL OPERATING REGIME OF AGRICULTURAL MACHINES FOR SEEDBED PREPARATION

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KEYWORDS: soil tillage machinery, optimization, operating regime, energy consumption, mathematical modeling, agricultural machinery operation

Chapter 1 INTRODUCTION

1.1.MOTIVATION FOR CHOOSING THE TOPIC

Machines and equipment for seedbed preparation loosen and level the topsoil layer in order to ensure optimal seed–soil contact at adequate moisture, thereby increasing the speed and quality of germination and contributing to yield stability and economic efficiency. From the rudimentary tools used hundreds of years ago to modern precision systems and conservation tillage practices, their role has been and remains decisive in the expansion of cultivated areas and in securing food for humanity. Among the most well-known and widely used agricultural machines and equipment for seedbed preparation today are plows, cultivators, levelers, harrows, rotary tillers, combiners, rollers, etc.

These implements operate in conjunction with agricultural tractors and rank among the largest fuel consumers on the farm, which makes it necessary to operate them under optimal conditions: highest possible quality indices, minimal energy consumption, and high productivity. The desired performance is achieved through experimental research that generates empirical models, as well as through mathematical modeling of the interdependencies among process factors (soil, working tool, speed, depth, compaction), models that have become solvable numerically with the development of computers. At present, including in view of the use of autonomous vehicles in agriculture, algorithms are needed (still lacking in most cases) to determine the optimal operating regime of tractor–implement aggregates (e.g., minimizing specific fuel consumption while maintaining seedbed quality), serving as the basis for automatic decisions regarding operating parameters.

1.2. OBJECTIVES OF THE THESIS

The topic of the doctoral thesis *"Research on the Development of Computational Algorithms for Determining the Optimal Operating Regime of Agricultural Machines for Seedbed Preparation"* has as its main objective the conduct of theoretical studies and the development of mathematical models that allow the elaboration of multi-criteria optimization algorithms for the operating regime of agricultural aggregates for seedbed preparation in field crops, verifiable through experiments, so as to obtain the best possible quality indices, minimal energy consumption, and high productivity.

The following specific objectives had to be achieved in order to fulfill the main objective:

- Analysis of the state of research regarding seedbed preparation;
- Analysis of optimization methods for technical systems and development of programs for numerical computation;
- Mathematical modeling of the energy consumption of plows;
- Mathematical modeling of the energy consumption of disc harrows;
- Conducting experimental research to determine the optimal working process of plows and validating the mathematical models;
- Conducting experimental research to determine the optimal working process of disc harrows and validating the mathematical models.

1.3. STRUCTURE OF THE DOCTORAL THESIS

The doctoral thesis comprises 6 chapters, 199 pages, 145 figures and graphs, 26 tables, 342 mathematical relations, a library containing 37 Python codes for numerical computation and optimization, and 112 bibliographic references.

Chapter 1 "INTRODUCTION" presents the motivation for choosing the thesis topic, the main objective and the specific objectives of the doctoral thesis, as well as a brief overview of its structure.

Chapter 2 "REVIEW OF RESEARCH ON SEEDBED PREPARATION" presents the level of development reached worldwide by mechanization technologies and seedbed preparation equipment. It reviews the physical and mechanical characteristics of agricultural soil specific to the seedbed, the

quality indices of seedbed preparation works, seedbed preparation technologies, and the main equipment currently used for seedbed preparation (subsoilers, plows, levelers, combiners). This chapter also highlights aspects related to the energy performance of equipment used for seedbed preparation, namely those intended for deep soil loosening, plowing, and soil leveling.

Chapter 3 "METHODS OF OPTIMIZING TECHNICAL SYSTEMS" discusses the necessity of developing mathematical models and computational algorithms for optimizing the processes carried out by technical equipment. It provides an analysis of the main optimization and numerical computation methods, complemented by a set of programs written in Python for each case. It includes theoretical elements and computational algorithms for linear process optimization problems, such as the primal simplex algorithm, the transportation problem, the stepping stone method, the minimum cost method, and the determination of the optimal solution. It also presents theoretical elements and computational algorithms for nonlinear optimization problems, including the Fletcher–Reeves method (conjugate gradients), the Davidon–Fletcher–Powell method, and geometric programming. Furthermore, it discusses theoretical elements and computational algorithms for the optimization of single-variable functions: the grid method, the Fibonacci method, the golden section method, polynomial optimization methods for single-variable functions (quadratic optimization, cubic optimization), as well as theoretical aspects of constrained single-variable function optimization. The chapter also presents theoretical elements and algorithms for the optimization of multivariable functions, such as optimization methods for unconstrained multivariable functions (random search method, random path method, one-dimensional search method) and constrained multivariable functions (Lagrange multipliers method, penalty function method). Finally, it covers the theoretical background and computational algorithms required for optimizing numerical functions, including linear regression and polynomial regression methods.

Chapter 4 "CONTRIBUTIONS TO THE ENERGY OPTIMIZATION OF AGRICULTURAL MACHINES FOR SEEDBED PREPARATION" presents: the systemic block diagram for the optimizable process of soil tillage by a tractor–machine aggregate, a classification of deterministic and stochastic processes in the case of agricultural aggregates, and particular aspects regarding the operation of agricultural machines for seedbed preparation. Of particular importance are the mathematical models developed for estimating the energy consumption of seedbed preparation machines (deep soil loosening equipment, plows, levelers, disc harrows). Emphasis is placed on mathematical models and computational algorithms (Python codes) for the mathematical modeling of the energy consumption of plows, which, by applying the Lagrange multipliers method, allow the determination of the optimal working width and speed of the plowing aggregate, as well as the required tractor power and the calculated energy consumption per unit area. Likewise, mathematical models and computational algorithms (Python codes) are presented for the mathematical modeling of the energy consumption of disc harrows in two operating variants (semi-mounted and mounted), enabling the calculation of the disc harrow's resistance force, the calculation of normal reactions on the tractor axles, the calculation of the tractor's driving force, and the calculation of the tractor's traction force when working in aggregate with the disc harrow, depending on the soil's physical and mechanical properties.

Chapter 5 "EXPERIMENTAL RESEARCH ON DETERMINING THE OPTIMAL OPERATING REGIME OF AGRICULTURAL MACHINES FOR SEEDBED PREPARATION" begins with general considerations on experimental research, including a review of the significance of the main statistical indicators. It then presents the objectives of the experimental research, specifying both the main and secondary objectives, as well as the general methodology of the experiments, and the measuring equipment and devices used in the trials. The chapter further presents the results of the experimental research aimed at determining the optimal working process of plows, using an agricultural aggregate composed of a tractor A 1800-A (180 HP) and a PP5VM plow (with 5 moldboards and variable working width), with the purpose of validating the

mathematical models and computational algorithms for determining the optimal operating regime of the plowing aggregate. Also included are the results of experimental research on determining the optimal working process of disc harrows, using an agricultural aggregate consisting of a U-650 tractor (65 HP) and, comparatively, a standard GD-3.2 disc harrow (semi-mounted in transport and trailed in operation), as well as a mounted disc harrow GD-3.2P (three-point linkage), with the aim of validating the mathematical models and computational algorithms for determining the optimal operating regime of the disc harrow aggregate.

Chapter 6 "CONCLUSIONS. PERSONAL CONTRIBUTIONS. PERSPECTIVES" presents the conclusions formulated on the basis of the theoretical and experimental research conducted within the doctoral thesis, the author's personal contributions regarding the development of computational algorithms for determining the optimal operating regime of agricultural machines intended for seedbed preparation, and proposals for future research in this field

Chapter 1 ANALYSIS OF THE STATE OF RESEARCH ON SEEDBED PREPARATION

2.1. Physical and mechanical characteristics of agricultural aoil

Soil is a polydisperse and heterogeneous system, composed of three phases: the gaseous phase, the liquid phase, and the solid phase (45% mineral, 5% organic) (Dictionary 1972). The properties of soil are divided into two categories (Koolen and Kuipers 1983, Canarache 1990) (Allire and Boyer 1995, Ancău and Nistor 1996):

- properties that influence both plant growth and development, referring to chemical and hydro-physical properties;
- properties that influence the action of machinery used in agricultural works, referring to physical-mechanical and physical properties.

The main physical properties of soil include: specific surface area, porosity, density and bulk density, structure, and texture (Koolen and Kuipers 1983, Canarache 1990).

- Soil porosity represents the ratio, expressed as a percentage, between the total volume of pores and the total volume of soil.
- Soil density is represented by the mass per unit volume of the solid phase.
- Bulk density is the volumetric mass calculated as the ratio between the mass of dry soil and the total volume of the sample collected in its natural state.
- Soil texture refers to the percentage proportion of the main particles in the composition of a soil. It represents the particle size distribution of the soil. For the classification of particles into several granulometric fractions, scales are used, the most common being the USDA scale and the Atterberg scale, presented in tables 2.1 and 2.2.

Table 2.1. *Grouping of soil particles into several granulometric fractions according to the USDA scale (Koolen and Kuipers 1983, Canarache 1990)*

Clay [mm]	**Dust [mm]**	**Fine sand [mm]**	**Medium sand [mm]**	**Coarse sand [mm]**	**Nisip foarte grosier [mm]**	**Skeletal material [mm]**
< 0,002	0,002 - 0,05	0,05 - 0,10	0,10 - 0,50	0,50 - 1,00	1,00 - 2,00	> 2,00

Table 2.2. *Grouping of soil particles into several granulometric fractions according to the Atterberg scale (Koolen and Kuipers 1983, Canarache 1990)*

Clay [mm]	**Dust [mm]**	**Fine sand [mm]**	**Medium sand [mm]**	**Coarse sand [mm]**
<0,002	0,002 - 0,02	0,02 - 0,20	0,20 - 2,00	>2,00

Soils are divided into textural classes, also known as textural types, according to their texture. In Romania, 10 textural classes are used, which are grouped into 5 categories, as shown in table 2.3 (Koolen and Kuipers 1983, Canarache 1990).

Table 2.3. *Classification of soils according to their texture (Koolen and Kuipers 1983, Canarache 1990)*

Category	**Textural type**	Clay [%]		Dust [%]
		< 0,01 mm	**< 0,002 mm**	**0,02 - 0,002 mm**
Fine	Clayey	> 71	> 61	> 33
	Clay loam	46 - 60	46 - 60	-
Medium fine	Silty clay loam	46 - 60	33 - 45	> 33
	Clay-silty loam	46 - 60	33 - 45	< 32
Medium	Silty loam	31 - 45	21 - 32	> 33
	Loam	31 - 45	21 - 32	15 - 30
	Sandy clay loam	31 - 45	21 - 32	< 14
	Sandy loam	< 20	< 12	> 33
Coarse medium	Loamy sand	11 - 20	6 - 12	< 32
Coarse	Sand	< 10	< 5	< 32

The main physical-mechanical properties of soil are represented by: friction, volume change, plasticity, consistency, adhesion, cohesion, and its deformation as a result of agricultural operations (resistance to plowing, resistance to penetration, resistance to cutting, resistance to compression) (Gill and Vanden Berg 1968, Augustin et al. 2019, Canarache 1990). Soil resistance to penetrability can be calculated using the formula:

$$\sigma_p = n \cdot \frac{G}{S} \quad [\text{Pa}] \tag{2.1}$$

where: *n* is the number of blows; *G* represents the applied weight, measured in N; *S* represents the maximum cross-sectional area at the penetration tip, measured in m².

Table 2.4. *Interpretation of results for soil penetration resistance (McKyes 1985, Canarache 1990)*

Evaluation	**Soil penetration resistance, [*kPa*]**
Easy	< 15
Medium	15 - 50
Hard	50 - 150
Very hard	> 150

Chemical properties of soils

Soil is a heterogeneous system in which solid matter occurs in various forms of dispersion. Both organic and mineral matter in the soil appear as fine particles with diameters of $\phi < 2$ μm, forming soil colloids. The colloidal complex consists of the entire set of colloids in the soil. It has the capacity to perform ion exchange and to adsorb various substances present in the soil solution (McKyes 1985)

2.2. Quality indices of seedbed preparation works

The quality indices of work are represented by a set of determinable or measurable values obtained using specific instruments, employed to evaluate a working process. In the case of seedbed

preparation works, these indices indicate the degree to which the agrotechnical requirements of the soil at the time of sowing are met (Brătucu 1999).

Table 2.5. *The interpretation of soil bulk density values refers to the evaluation of soil density according to its structure and degree of loosening (McKyes 1985, Canarache 1990).*

Volumetric mass, [g/cm^3]	**Interpretation**
1,30 - 1,40	Strongly compacted plow layer
1,20	Compacted plow layer
1,00 - 1,10	Plow layer
Sub 1,00	Soil rich in organic matter or very loose

Table 2.6. *Reference values for the quality indices of seedbed preparation works* (Constantinescu and Popescu 2009, Şandru 1983)

Quality indices of seedbed preparation works	**Values**
Degree of weed destruction	$G_{db} > 95{,}00$ %
Degree of soil crumbling	$G_{ms} > 75{,}00$ %
Coefficient of variation of working depth	$C_a \leq \pm 0{,}10$
Standard deviation of working depth	$s_a \leq \pm 0{,}10\ a_m$
Maximum deviation from average working depth	$\Delta_a \leq \pm 0{,}20\ a_m$
Mean deviation from average working depth	$\delta_a \leq \pm 0{,}10\ a_m$
Quality indices of basic tillage works	**Valori**
Degree of weed destruction	$G_{db} > 90{,}00$ %
Degree of soil crumbling	$G_{ms} > 70{,}00$ %
Coefficient of variation of working depth	$C_a \leq \pm 0{,}10$
Standard deviation of working depth	$s_a \leq \pm 0{,}10\ a_m$
Maximum deviation from average working depth	$\Delta_a \leq \pm 0{,}20\ a_m$
Mean deviation from average working depth	$\delta_a \leq \pm 0{,}10\ a_m$

2.3. Technologies for seedbed preparation

Soil is the medium in which plant roots develop and is a natural body in continuous evolution, influenced by environmental factors and human intervention.

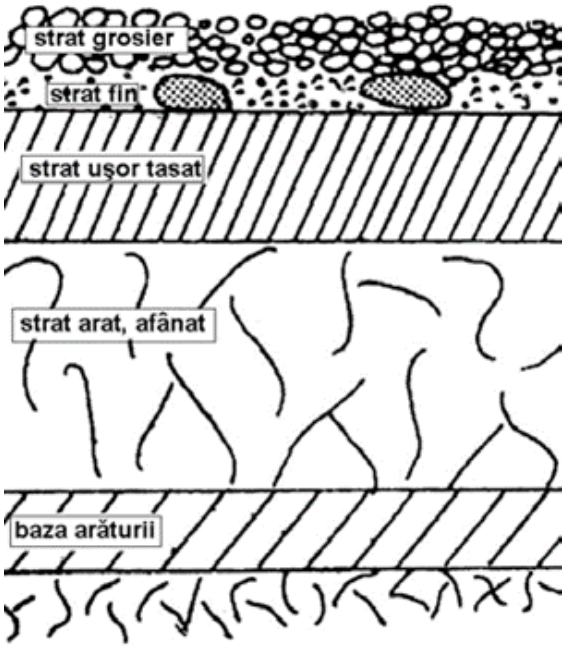


Figure 2.1. *Seedbed layers (Naghiu 2004)*

The prepared seedbed (Figure 2.1) meets the following agrotechnical requirements (Ciulu and Bârcă 2002):

- the soil surface must be maintained in a coarser state to prevent crust formation that could hinder plant emergence;
- the soil layer intended for seed placement must be fine, so that nearby water can come into contact with the seeds and provide the moisture necessary for germination;
- the soil layer on which the seeds are placed must be lightly compacted to support the vertical growth of the plant;
- for optimal root development, the base of the seedbed must be deeply loosened, ensuring both an adequate air–water regime and the presence of nutrients essential for plant growth.

Modern technologies include a series of operations for land preparation, applicable to each cropping system: seedbed preparation for sowing, autumn plowing, basic fertilization, supply irrigation, leveling, soil loosening, and removal of plant residues. However, depending on the type of crop, these operations are applied in different ways (Ciulu 2000, Bodolan and Brătucu 2013, Drăguțan and Demetrescu 1984).

2.4. Equipment for seedbed preparation

Soil tillage machines are classified according to the way their working tools are driven, as follows (Căproiu Șt. 1982, Manian and Kathirvel 2001):

- machines equipped with mobile working tools driven by the soil;
- machines equipped with mobile working tools with rotary or vibrating motion, driven by the tractor's power take-off;
- machines equipped with dragged working tools.

2.4.1. Equipment for deep soil loosening – subsoilers

Deep loosening is a soil tillage operation that involves breaking up the sub-arable layer without inverting it (Cojocaru, Marin and Voicu 2006, Marin 2011, Mitroi 1994, Upadhyay and Raheman 2020, Vlad 2013). The purpose of this operation is to improve soil aeration, facilitate deep water infiltration, and create optimal conditions for root development, including the destruction of the hardpan.

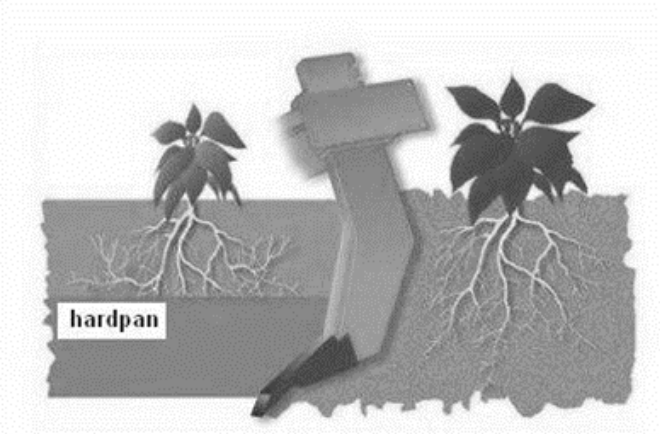


Figure 2.2. *Effect of deep loosening on soil (Ciulu and Bârcă 2002)*

Deep soil loosening is carried out at a depth of 45–55 cm and is recommended at least once every two years. At the same time, operations such as fertilizer incorporation or the construction of "mole" drains can also be performed (Croitoru et al. 2017).

Deep soil loosening is carried out on dry land, at a moisture content between 60–80% of field capacity, in order to ensure the adhesion of the driving wheels and the traction force required to operate the subsoiler (Ciulu and Bârcă 2002).

2.4.2. Equipment for plowing – plows

The plow is the agricultural implement used for plowing, a process that involves breaking the soil into furrows, crumbling them, and inverting them at a predetermined depth in the arable layer, thereby ensuring optimal conditions for plant development.



Figure 2.3. *Construction of a mounted plow with 5 moldboards* (Teșu 1984)

Plows (Figure 2.3) are composed of the following main parts: the working elements—namely coulters, moldboards, skimmers, and shares—which perform the plowing operation, and the auxiliary elements—namely wheels, axles, the frame, the tractor hitch triangle, and mechanisms that ensure the fastening and adjustment of the working elements.

2.4.3. Equipment for soil leveling – levelers

Leveling is the agricultural operation aimed at obtaining a uniform surface of the agricultural land, carried out either as major leveling or as maintenance leveling (Dictionary 1972).



Figure 2.4. *Trailed leveler [https://losantonios.com/ro/lame-de-nivelare/]*

The leveler is supported by its support wheels during operation. As the machine moves, the cutting edge of the blade acts like a wedge, penetrating the soil to the adjusted working depth and detaching a layer of soil from the uneven surface.

2.4.4. Complex equipment for seedbed preparation – combiners

Combiners are agricultural implements equipped with various working tools (shares, tines, spikes, chisels, stars, etc.) that act successively on the upper soil layer, performing operations of crumbling, loosening, and smoothing. They are used in soil tillage operations for preparing the land for sowing (Scripnic and Babiciu 1979).

In general, combiners (Figure 2.5) consist of a vibrocultivator A (a cultivator for complete soil tillage), composed of: frame 1, coupling device to the power source 2, working depth control wheels 3, loosening tools 4, and a helical harrow B consisting of frame 5, two rod rotors 6, and the leveling adjustment system 7.

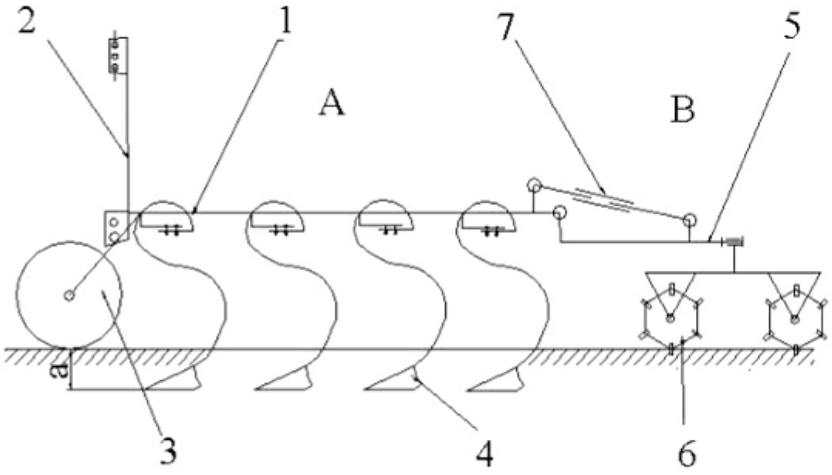


Figure 2.5. *General scheme of a vibro-combiner* (Căproiu Şt. 1982)

2.5. Energy performance of seedbed preparation equipment

Soil preparation is a very important operation for ensuring optimal conditions for plant growth and development, but it also represents a significant energy consumption (Brătucu 2006, Srivastava et al. 2006).

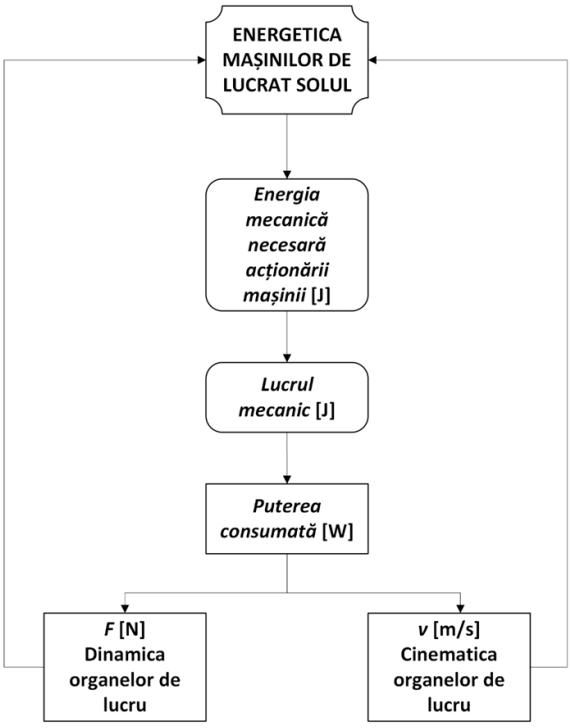


Figure 2.6. *Block diagram for the study of the energy performance of soil tillage machines* (Ciulu și Bârcă 2002)

Energetics analyzes the mechanized technological process from the perspective of the use and exploitation of different forms of energy (Brătucu 2007, P. Okoko 2017). The theoretical study of the energy performance of soil tillage machines consists in determining and calculating the energy components required for soil processing (Constantinescu, Popa and Dumitru 2006, Boruz 2005, Kheiralla et al. 2004, Lekavičienė et al. 2019)

The mechanical energy required for soil tillage is expressed by the following relation (Ciulu and Bârcă 2002) (Constantinescu 2005*)*:

$$E_t = E_{lucrare} + E_{pierderi} \ [J] \tag{2.2}$$

where: Et – total mechanical energy used to operate the machine, measured in J; Elucrare – energy used to carry out the mechanized working processes, measured in J; Epierderi – energy lost in the machine transmission due to friction (Brătucu 1999, Brătucu 2010).

Thus, the study of the energy performance of soil tillage machines is reduced to the study of the power consumed by the machines (Figure 2.6) (Ciulu and Bârcă 2002, Kurach and Amantayev 2020).

The consumed power is calculated as the product between the forces acting on a machine during soil tillage, F, and the travel speed, v, according to the relation (Kheiralla et al. 2004):

$$P = F \cdot v \ [W] \tag{2.3}$$

2.5.1. Energy performance of deep soil loosening equipment

Subsoilers are used for deep soil loosening. This operation contributes to improving aeration, facilitating water infiltration into deeper layers, and creating optimal conditions for root development (Rus 1987).

The subsoiler can be operated through the tractor's traction force. The working process of the subsoiler involves both the vertical shank and the share. The share acts as a simple wedge that displaces the soil, separates it from the bottom of the furrow, then lifts and finally crumbles it. A deformation zone is formed in front of the working tool, where the soil is loosened (Ghereș and Roș 2007). The vertical shank of the subsoiler can split and laterally displace the soil from this zone, creating a furrow. The share is mounted at an angle α relative to the horizontal in order to cut the soil by sliding (Gill and Vanden Berg 1968, Anpat and Raheman 2017).

During the working process, the cutting edge of the share slices the soil under the action of the traction force, *Ft* (Ciulu and Bârcă 2002, Mamman and Oni 2005). The soil resists through the normal pressing force, *N* (Carol 1980, Căproiu 1982). Considering these forces, the value of the force required for moving the wedge (*Fshare*) is calculated using the following relation (Ghereș and Ghereș 2013, Ciulu and Bârcă 2002, Harrigan and Rotz 1994):

$$F_{brazdar} = N' \cdot \sin(\alpha + \varphi) + R_N \cdot tg\varphi_1 = \frac{N}{cos\varphi} \cdot \sin(\alpha + \varphi) + R_N \cdot \mu_1 \quad [N] \tag{2.4}$$

The energetics of subsoilers analyzes the energy consumption associated with each mechanized operation performed by the subsoiler. Soil tillage using the subsoiler involves significant energy consumption (Perdok and Kouwenhoven 1994). It is therefore necessary to evaluate all factors that may influence this consumption, in order to identify methods for its reduction..

The total energy required for soil tillage with the subsoiler can be expressed by the following relation: (Ghereș and Roș 2007*):*

$$E_t = E_{subsolier} + E_{pierderi} \quad [J] \tag{2.5}$$

where: *Esubsoiler* is the energy required for deep soil loosening, J; *Epierderi* – the energy consumed by losses in the machine mechanism, J.

The power required to operate subsoilers, Ps, has three components, namely (Ghereș and Roș 2007):

$$P_s = P_d + P_t + P_{dsp} \quad [W] \tag{2.6}$$

where: *Pd* – represents the power required for moving the machine, measured in W; *Pt* – represents the power required for cutting and displacing the soil, measured in W; *Pdsp* – represents the power required for splitting the displaced soil, measured in W (Ciulu and Bârcă 2002).

2.5.2. Energy performance of plowing equipment

As the tractor–plow aggregate advances, the moldboard cuts the soil into furrows with width *b* and depth *a*. These furrows are lifted onto the active surface of the moldboard, crumbled, and then inverted laterally, having a cross-section of $a \times b$ (Figure 2.7) (Scripnic and Babiciu 1979, Babiciu and Biriș 1998).

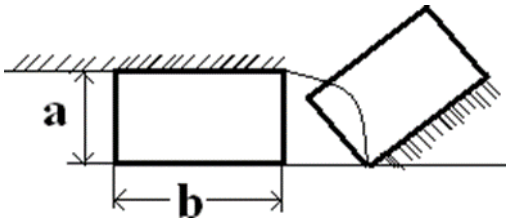


Figure 2.7*. Working mode of the moldboard* (Scripnic și Babiciu 1979) (Ancău și Nistor 1996)

The draft resistance is determined using the Goriatchkin formula proposed for moldboard plows. This formula reflects the physical essence of the working process performed by the moldboard (Ghereș 2014):

$$R_{arat} = f \cdot G_{plug} + k \cdot a \cdot b \cdot n + \varepsilon \cdot a \cdot b \cdot n \cdot v_m^2 \quad (2.7)$$

The formula is composed of three terms, R_d, R_{taiere}, $R_{aruncare}$:

$$\begin{cases} R_d = f \cdot G_{plug} \\ R_{taiere} = k \cdot a \cdot b \cdot n \\ R_{aruncare} = \varepsilon \cdot a \cdot b \cdot n \cdot v_m^2 \end{cases} \quad (2.8)$$

where: *Rd* – represents the resistance to forward movement, measured in N; *Rtăiere* – represents the resistance to soil cutting, lifting, and breaking, measured in N; *Raruncare* – represents the resistance to throwing the displaced soil, measured in N.

The total energy required for soil tillage with the plow can be expressed by the following relation (Ghereș and Roș 2007):

$$E_t = E_{arat} + E_{pierderi} \quad [J] \quad (2.9)$$

where: E_{arat} – represents the energy required for soil tillage with the plow, measured in J; $E_{pierderi}$ – represents the energy consumed by losses in the machine mechanism, measured in J.

The required energy can be determined using the following relations (Gheres și Roș 2007):

$$E_{arat} = L_{arat} = P_{arat} \cdot t_{arat} \quad [J] \quad (2.10)$$

where: L_{arat} – represents the mechanical work consumed in plowing, measured in J; t_{arat} – represents the time required to perform the plowing operation, measured in s.

Equation (2.9) becomes:

$$E_t = P_{arat} \cdot t_{arat} + E_{pierderi} \quad [J] \quad (2.11)$$

The power required to operate the plow, P_{arat}, has three components (Gheres și Roș 2007):

$$P_{arat} = P_d + P_t + P_a \quad [W] \quad (2.12)$$

where: *Pd* represents the power required for moving the plow, W; *Pt* represents the power required for cutting the soil, W; *Pa* represents the power required for throwing the soil, W.

The driving power for the plow can be calculated as:

$$P_{arat} = f \cdot G_{plug} \cdot v_m + k \cdot a \cdot b \cdot v_m + \varepsilon \cdot a \cdot b \cdot v_m^3 \quad [W] \qquad (2.13)$$

The total energy required to operate the plow can be calculated using the relation:

$$E_{arat} = f \cdot G_{plug} \cdot v_m \cdot t_{arat} + k \cdot a \cdot b \cdot v_m \cdot t_{arat} + \varepsilon \cdot a \cdot b \cdot v_m^3 \cdot t_{arat} + E_{pierderi} \quad [J] \qquad (2.14)$$

2.5.3. Energy performance of soil leveling equipment

Soil tillage using the leveler involves a relatively low energy consumption. However, it is necessary to analyze all factors that influence energy consumption in order to identify methods for its reduction. The total energy required for soil tillage using the leveler can be expressed by the following relation: *(Ciulu și Bârcă 2002):*

$$E_t = E_{niv} + E_{pierderi} \quad [J] \qquad (2.15)$$

where: E_{niv} – represents the energy required for soil leveling, measured in J; $E_{pierderi}$ – represents the energy consumed by losses in the machine mechanism, measured in J..

But:

$$E_{niv} = L_{niv} = P_{niv} \cdot t_{niv} \quad [J] \qquad (2.16)$$

where: L_{niv} – mechanical work consumed in soil leveling, J; P_{niv} – power required to perform leveling, W; t_{niv} – time required to perform leveling, s.

Chapter 3 METHODS OF OPTIMIZING TECHNICAL SYSTEMS

3.1. General considerations

Optimization activity practically encompasses all fields of work. To solve an optimization problem, two phases must be followed: the development of the mathematical model of the process and the search for the optimum (Nădejde 1971). A mathematical model, in the general sense, is an abstract scheme built with the help of mathematical symbols and signs, which expresses the working process of a machine, installation, or agricultural aggregate, a mechanization technology, or any other activity (Dobrescu 1981). The mathematical model must characterize the essential properties of the object under study, being free of details and particularities. In conclusion, a mathematical model is presented through a system of equations that interconnect the parameters characterizing the essential elements for the intended purpose (Simionescu, Dranga and Moise 1995).

In the optimization process, the so-called optimization criteria are taken into account. These may be: maximum working capacity of aggregates, minimum energy consumption per unit of work performed, minimum fuel consumption per unit of work performed, minimum power of the aggregate's energy source, reduced aggregate mass, reduced labor requirement, minimum material consumption per unit of work performed, minimal harvest losses, superior quality indicators, maximum aggregate reliability, minimum service life of machinery, maximum comfort conditions, minimum costs per unit of work performed, maximum profit, maximum efficiency, etc. (Dobrescu 1981).

The mathematical model consists of: the objective function and the constraints (Anderson et al. 2017). The objective function expresses the functional relationship between the parameters of the aggregate or technological installation and the optimization criterion. The constraints represent the linking conditions between the process parameters and the utilization indicators (Bebea 1978).

Optimization problems are divided into two major categories (Cârlan 1994):

- optimization of linear problems, in which the objective function and constraints are linear;
- optimization of nonlinear problems, in which the objective function is nonlinear.

3.2. Optimization of linear processes

Linear programming is one of the most frequently encountered optimization methods in all fields of activity. The purpose of linear programming is to determine the minimum or maximum value of a linear function, called the objective function, in the presence of constraints expressed by linear equations or inequalities (Şerban and Dumitrescu 1998, Mihu 1977).

The best-known method for solving a linear programming problem uses the primal simplex algorithm, established in 1948 by Dantzig (Simionescu, Dranga and Moise 1995).

Primal simplex algorithm

The simplex algorithm for linear programming is a two-phase procedure for determining an optimal solution. In the first phase, an initial basic solution is found or information is obtained that such a solution does not exist. In the second phase, the basic solution obtained in the first phase is used as a starting point to determine a minimum point or to indicate that the minimum is unbounded (Lasdon 1975).

The transportation problem

Quite often, certain linear programming problems can be solved much more easily using algorithms specialized for those problems. Thus, if a given product is available in quantities $a_1, a_2, \ldots, a_m$ at warehouses $A_1, A_2, \ldots, A_m$ called sources, and it must be transported in quantities $b_1, b_2, \ldots, b_n$ to warehouses $B_1, B_2, \ldots, B_n$ called destinations, while requiring that the transportation be carried out at minimum cost, a specific algorithm can be generated for this class of problems that will lead to an admissible solution (Iaciu 2003).

Minimum cost method

In the case of the minimum cost method, used to determine the initial basic solution, the costs c_{ij} are also taken into account. Thus, in the first step, the component x_{kl} is determined for which $c_{kl} = min(c_{ij})$. In the table, the value $x_{kl} = min(a_k, b_l)$ is entered. In the next step, the procedure is repeated for the reduced table. Often, the minimum cost method provides a better initial basic solution than the stepping-stone (diagonal) method, so that the number of iterations required to improve the initial basic solution, i.e., to determine the minimum, is smaller or even equal to zero (Iaciu 2003).

Determining the optimal solution. Algorithm description.

To determine the optimal solution, given an initial basic solution, a specific algorithm for the transportation problem is used. Thus, a number of cycles equal to the number of free locations is constructed. Such a cycle starts from a free location, say (i, j), follows a rectangular path such that only occupied cells are at the corners, and returns to the same starting location. In each corner of the cycle, the indices of the respective location are entered, enclosed in parentheses, together with the cost associated with that cell.

To test the optimality of the solution, in the cell corresponding to the variable x_{ij}, the quantity δ_{ij} is entered, equal to the algebraic sum with alternating signs of the costs appearing in the cycle (i, j), starting with $+c_{ij}$. If cells result in which the δ_{ij} values are negative, this means the solution is not optimal and must be improved. The corresponding modification of the solution is carried out by assigning the component x_{ij} a nonzero value θ. The magnitude of θ must be chosen so that, when subtracted and added to the variables of the cycle in question—according to how the costs were subtracted and added for the determination of δ_{ij}—no negative values result (the limiting case being when the value of a cell can be zero) (Dancea 1976).

3.3. Nonlinear optimization

Nonlinear optimization is used for mathematical models in which the objective functions have a nonlinear form (Simionescu, Dranga and Moise 1995). These objective functions may depend on a single independent variable or on n independent variables, where $n \geq 2$ (Dancea 1976). At the same time, nonlinear optimization may be with or without constraints (Lasdon 1975). The specialized literature mentions numerous methods for solving nonlinear optimization problems, a few of which are presented in this section.

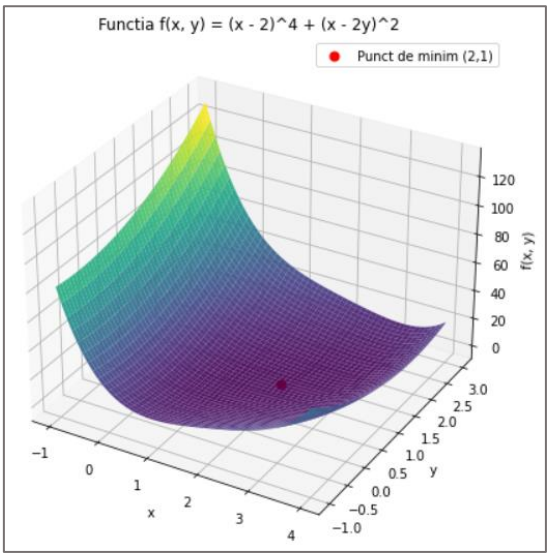


Figure 3.1. *3D representation of the function f(x,y) and the minimum point using the Fletcher–Reeves method and the Davidon–Fletcher–Powell method*

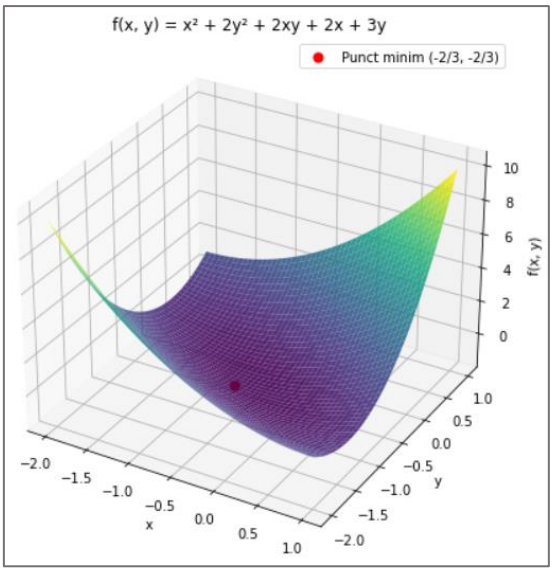


Figure 3.2. *3D representation of the function f(x,y) and the minimum point using the Davidon–Fletcher–Powell method*

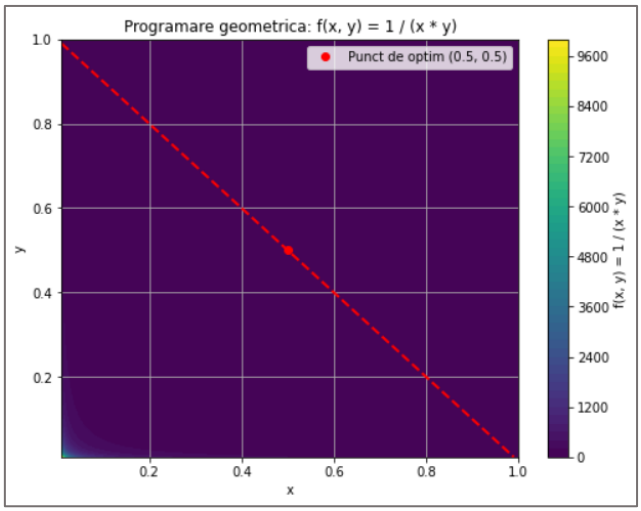


Figure 3.3. *2D representation of the function f(x,y) and the optimum point using geometric programming*

3.4. Optimization of single-variable functions

The determination of the minimum (maximum) of a single-variable function *f(x)* can be carried out, as is known from mathematical analysis, by solving the equation (Dancea 1976, Dragușin, Drăgușin and Câslaru 1993):

$$\frac{df(x)}{dx} = 0. \qquad (3.1)$$

For the application of this method, the function must be differentiable on the interval in which the minimum point is located, and the analytical expression of the derivative should be as simple as possible (Ixaru 1979). Therefore, in some cases this method is very cumbersome, which requires the use of simpler, more intuitive methods that do not involve the analytical solution of equation (3.107). A few approximate methods for determining the minimum of a function are presented below.

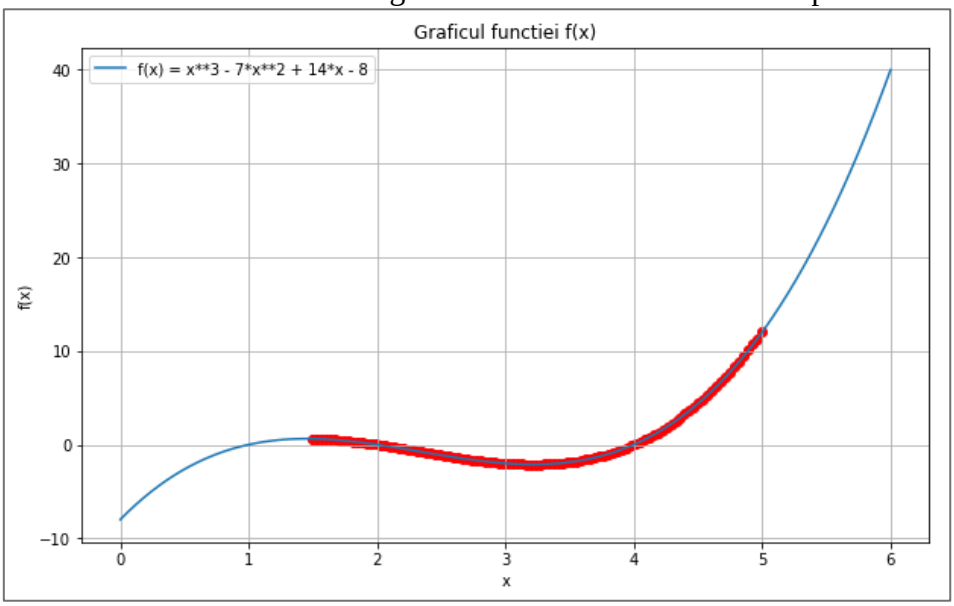


Figure 3.4. *2D representation of the graph of a single-variable function using the Grid method*

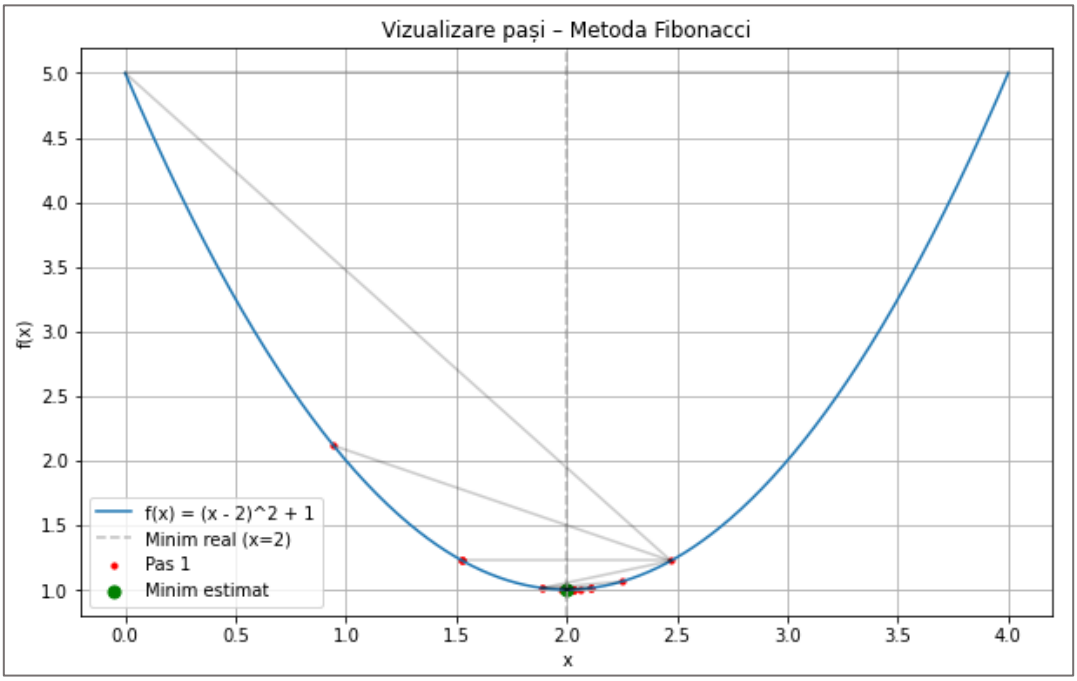


Figure 3.5. *2D representation of the graph of a single-variable function and the steps followed to identify the minimum point using the Fibonacci method*

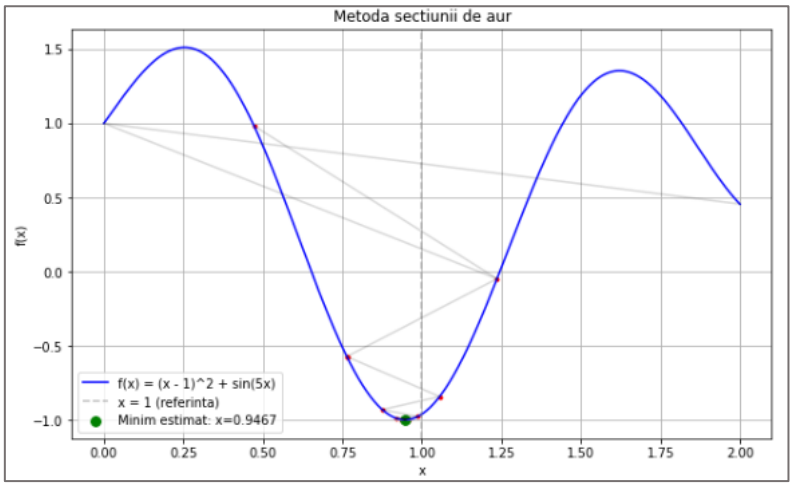


Figure 3.6. *2D representation of the graph of a single-variable function and the steps followed to identify the minimum point using the golden section method*

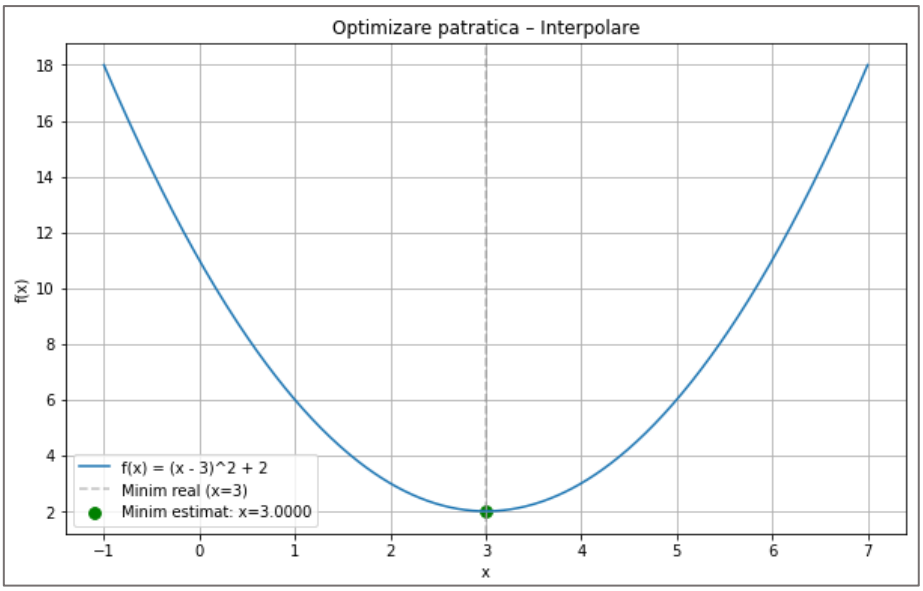


Figure 3.7. *2D representation of the graph of a single-variable function and the steps followed to identify the minimum point through quadratic optimization*

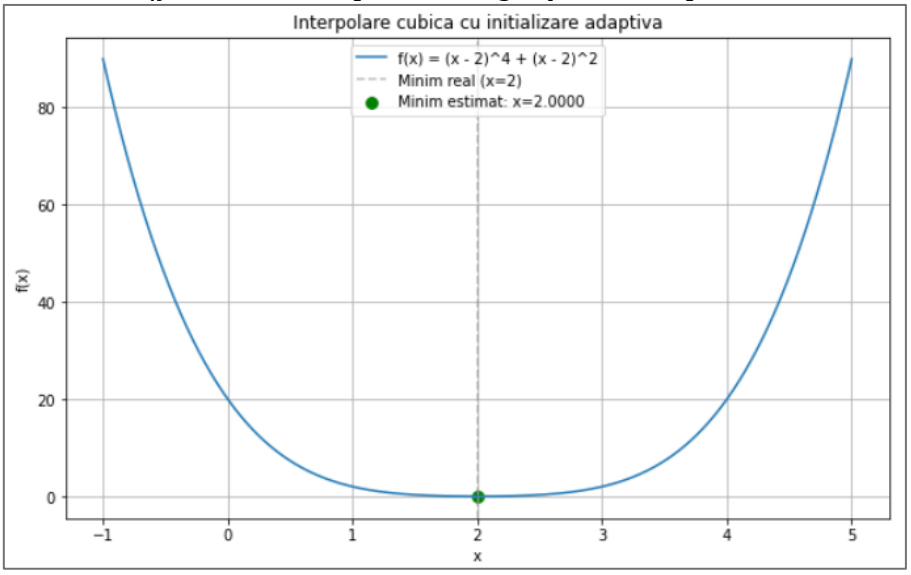


Figure 3.8. *2D representation of the graph of a single-variable function for identifying the minimum point through cubic optimization*

3.5. Optimization of single-variable functions with constraints

The mathematical model for a constrained minimization problem of a single-variable function is presented as follows (Dancea 1976):

to minimize f(x), (3.2)

subject to the constraints $g_j(x) \leq 0, j = \overline{1,m},\ x > 0.$ (3.3)

These optimization methods, in which the determination of the optimum point starts from a small value of the penalty parameter and then sequentially increases its value while solving at each step an unconstrained optimization problem, are called Sequential Unconstrained Minimization Techniques, or more briefly SUMT.

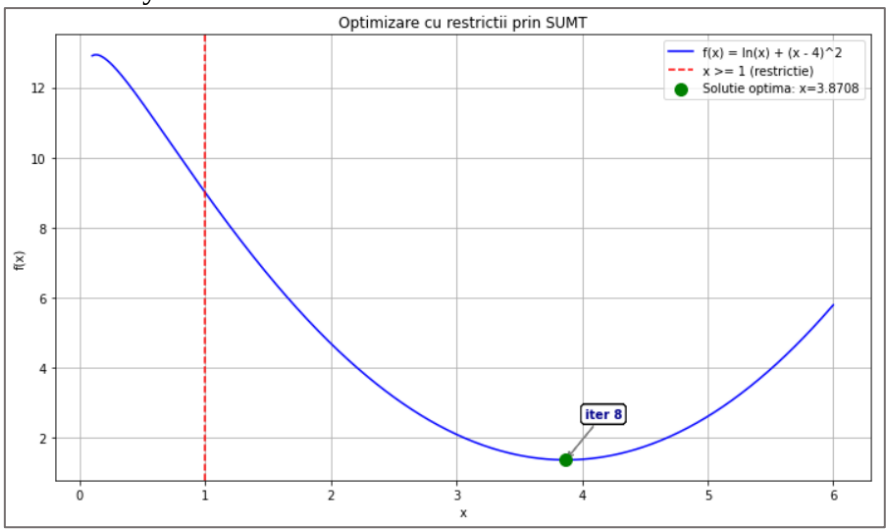


Figure 3.9. *2D representation of the graph of a single-variable function for constrained function optimization using SUMT*

3.6. Optimization of multivariable functions

3.6.1. Unconstrained optimization of multivariable functions

In practice, many problems require determining the minimum of a function f(x), where x = (x_1, x_2, …, x_n), without imposing additional conditions on the variables. In this respect, both methods that require only the evaluation of the function and methods that use information related to the gradient of the objective function are employed. (Ancău și Nistor 1996, Dancea 1976, Lasdon 1975, Malița și Zidăroiu 1975, Smigelschi și Woinaroschy 1978).

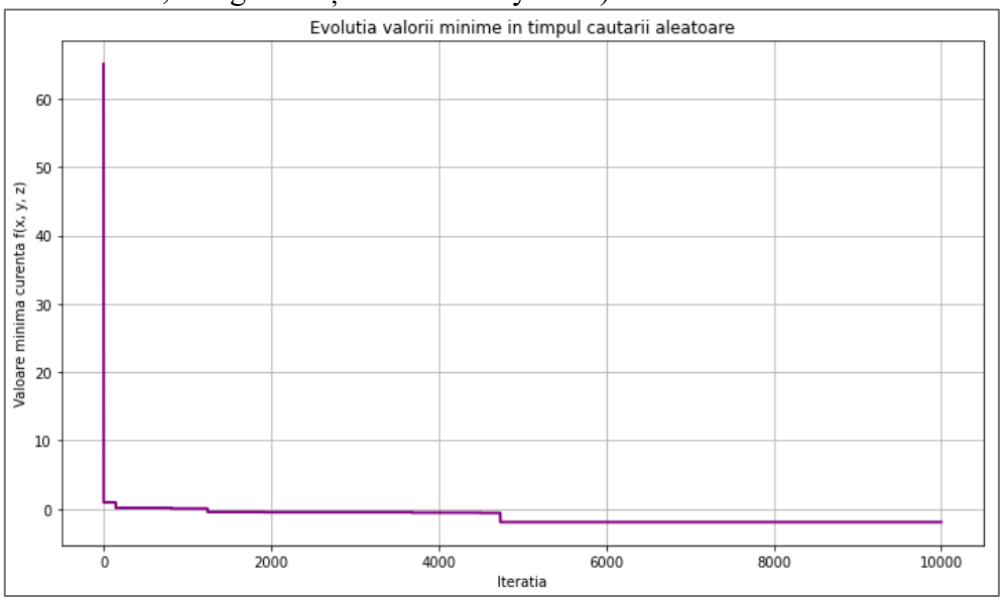


Figure 3.10. *Representation of the evolution of the minimum value during random search in the case of unconstrained multivariable functions*

The random search method determines the global minimum of a function of n variables and is based on generating a set of random numbers within a predetermined domain (Dancea 1976). The values of the variables with respect to which the function is defined are chosen using random numbers. In this respect, at each iteration of the minimization process, a sequence of random numbers is generated with uniform probability density within the admissible variation domain. Using these random numbers, the values of the variables of the objective function are established. For all these vectors, the values of the objective function are determined, and the vector for which the function has the minimum value is retained. Subsequently, the domain is narrowed around the identified minimum point, and the process is repeated for a new iteration.

The random path method also uses random numbers in the search for the minimum of the objective function; however, the determination of the vector of the function variables is carried out using the relation (Dancea 1976):

$$x^{(k+1)} = x^{(k)} + \gamma \cdot r \qquad (3.4)$$

where: *x^(k)* – is the position vector of the approximation point at iteration *k*; γ – a scalar; *r* – a unit vector with random direction.

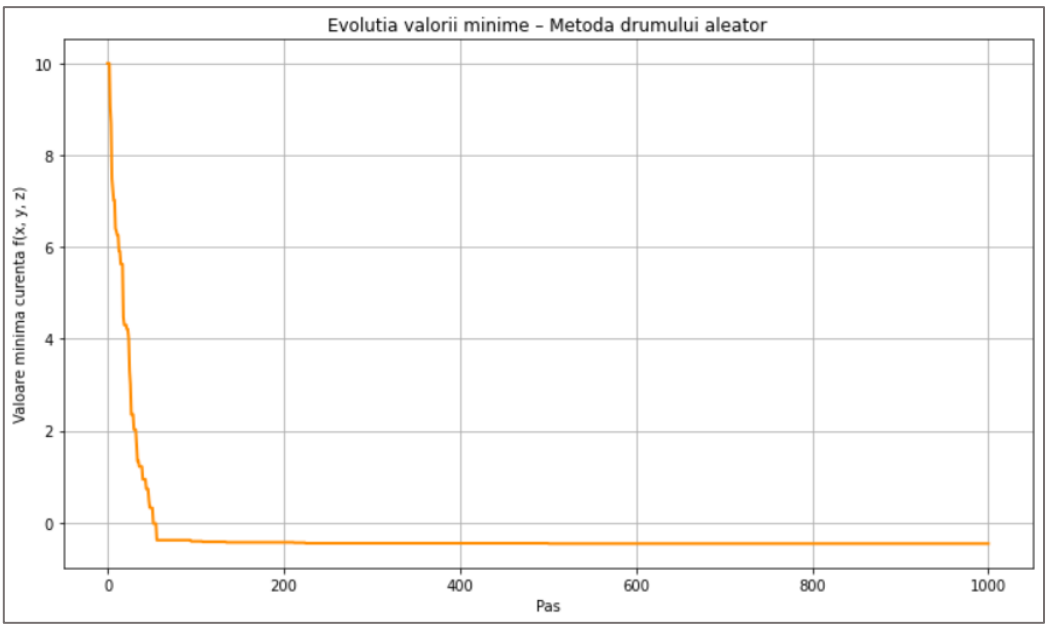


Figure 3.11. *Representation of the evolution of the minimum value during the search using the random path method*

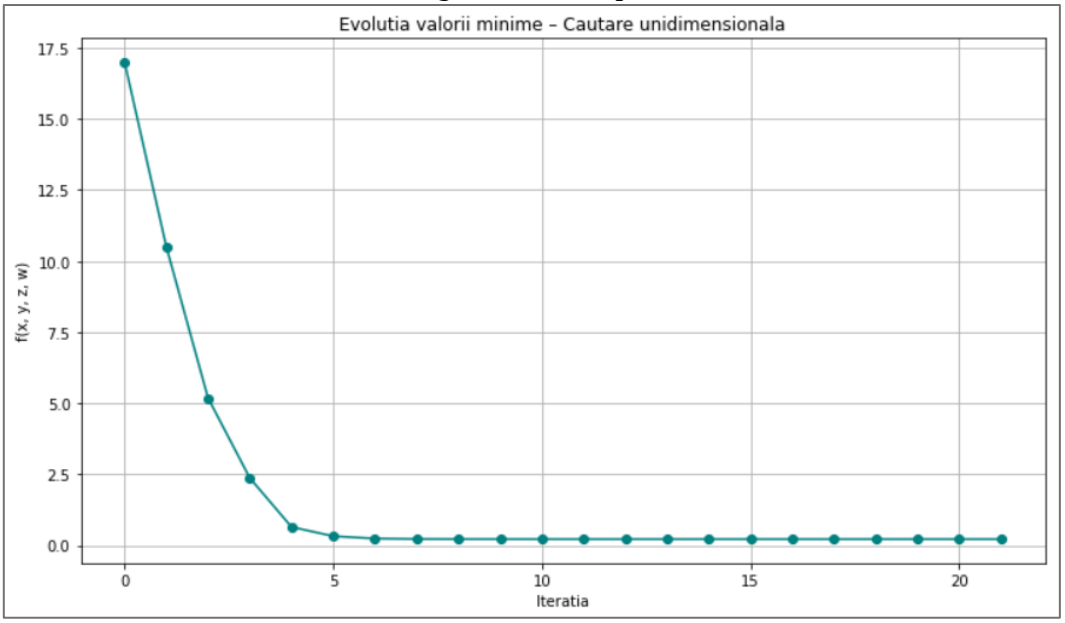


Figure 3.12. *Representation of the evolution of the minimum value in the case of the one-dimensional search method*

The one-dimensional search method determines the minimum of the function *f(x)* by successively modifying the components of the vector *x* (Dancea 1976). The minimization process starts with the increment of the first component, x_1, while the others remain constant as long as the function *f(x)* decreases.

Next, the second component of the vector *x* is incremented, and so on. When all components have been modified, a cycle is considered complete. The minimization process of the objective function then resumes with the increment of the first component again, after the increment has been reduced, thus performing a number of complete cycles until the function *f(x)* reaches a minimum value.

3.6.2. Constrained optimization of multivariable functions

Lagrange multipliers method

It involves finding the minimum (maximum) of an objective function (Dancea 1976):

$$f(X) = f(x_1, x_2, \dots, x_n) \tag{3.5}$$

subject to the conditions

$$g_j(X) = g_j(x_1, x_2, \dots, x_n) \leq= 0, \;\; j = \overline{1,m}, \tag{3.6}$$

Where $m < n$. It is assumed that both the objective function and the constraints admit first-order partial derivatives with respect to the variables x_i, $i = 1,\dots,n$.

The Lagrange multipliers method consists in considering an auxiliary function $F : \mathbb{R}^{n+m} \to \mathbb{R}$, of the form:

$$F(X, \lambda) = f(X) + \sum_{j=1}^{m} \lambda_j g_j(X) \tag{3.7}$$

where λ_1, λ_2, …, λ_m are Lagrange multipliers. The necessary condition for the minimum of the function $F(X, \lambda)$ consists in the vanishing of the first-order partial derivatives, that is (Lasdon 1975, Carol 1980):

$$\frac{\partial F}{\partial x_i} = \frac{\partial f}{\partial x_i} + \sum_{j=1}^{m} \lambda_j \frac{\partial g_j}{\partial x_i} = 0, \;\; i = \overline{1,n};$$
$$\frac{\partial F}{\partial \lambda_j} = g_j(X) = 0, \; j = \overline{1,m} \tag{3.8}$$

or:

$$\frac{\partial f}{\partial x_1} + \lambda_1 \frac{\partial g_1}{\partial x_1} + \lambda_2 \frac{\partial g_2}{\partial x_1} + \cdots + \lambda_m \frac{\partial g_m}{\partial x_1} = 0;$$
$$\frac{\partial f}{\partial x_2} + \lambda_1 \frac{\partial g_1}{\partial x_2} + \lambda_2 \frac{\partial g_2}{\partial x_2} + \cdots + \lambda_m \frac{\partial g_m}{\partial x_2} = 0;$$
$$\dots\dots\dots

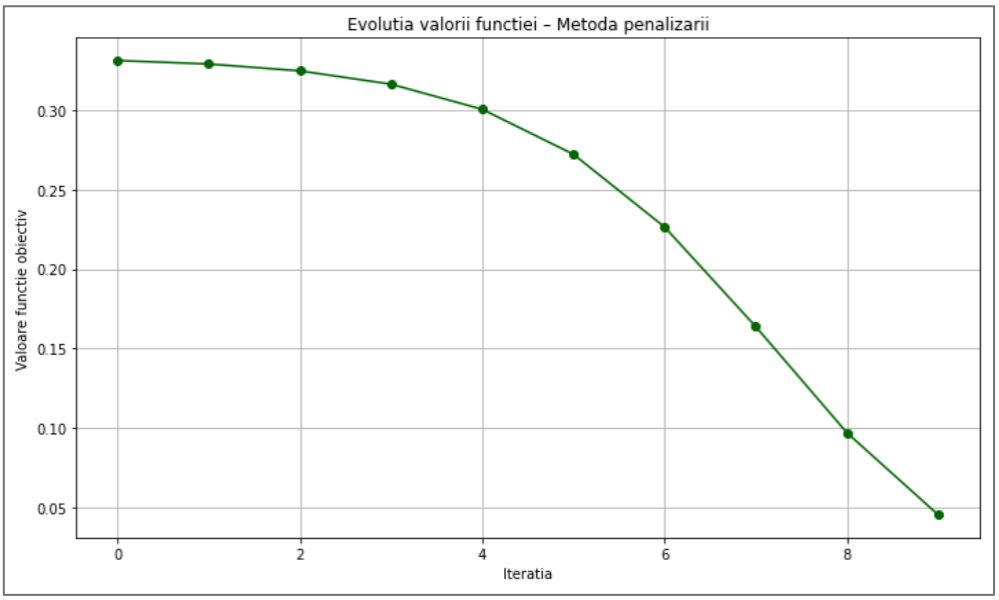


Figure 3.13. *Representation of the evolution of the function value in the case of the penalty method*

3.7. Optimization of numerical functions

In the case of numerical functions, there are situations where they must be approximated by analytical functions, while at the same time the phenomenon under study must be represented as accurately as possible (Dancea 1976). If the number of points for which the function values are known is small, this approximation can be done using interpolation polynomials (Newton forward, Newton backward, Gauss forward, Gauss backward, Lagrange) or with the help of special functions such as Hermite, Chebyshev, Laguerre, or Legendre. If the number of such points is very large, the computational effort required to determine the coefficients of the interpolation polynomials becomes very high, leading to significant truncation and rounding errors. Furthermore, when collecting experimental data corresponding to a certain phenomenon, various inherent errors occur, resulting in a function that does not best represent the process under consideration (Lasdon 1975).

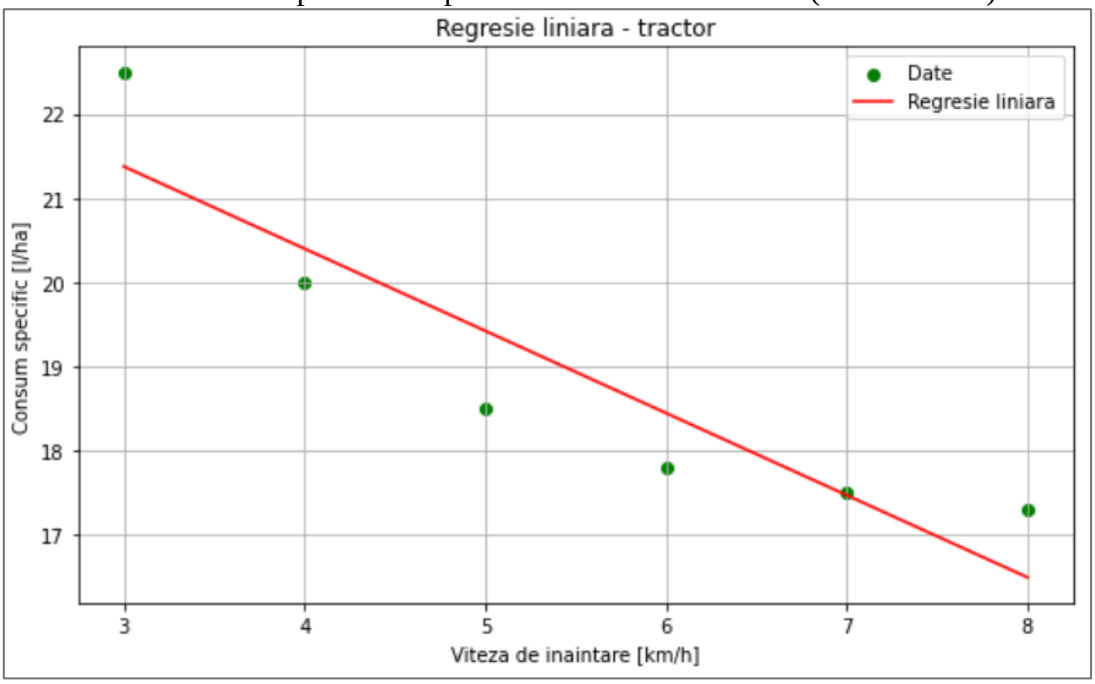


Figure 3.14. *Representation of the evolution of the function value in the case of linear regression*

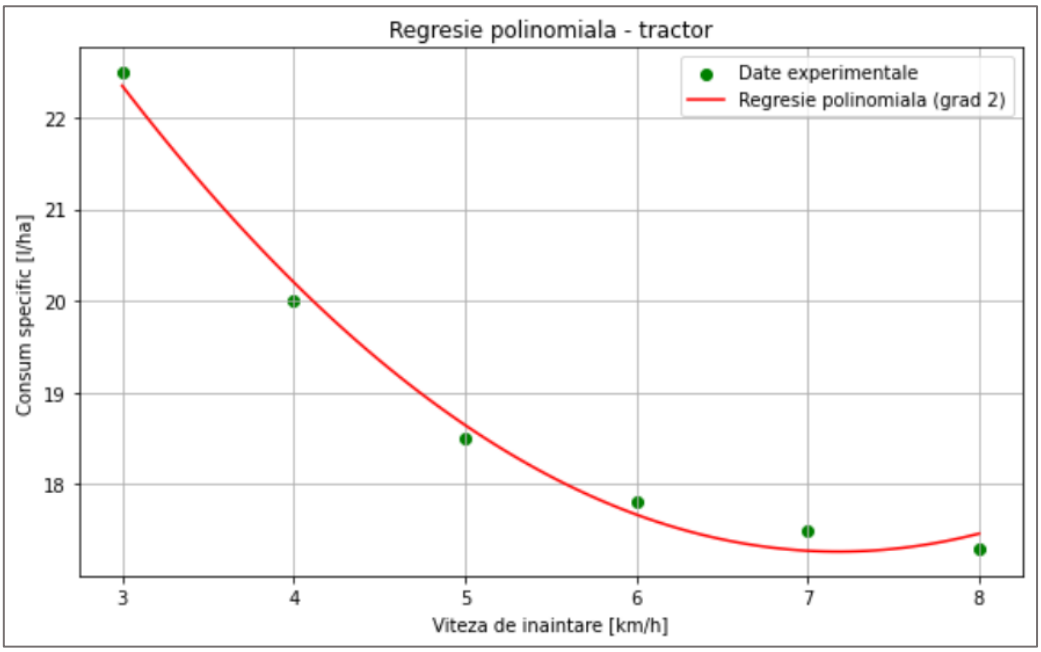


Figura 3.15. *Representation of the evolution of the function value in the case of polynomial regression*

Chapter 4 CONTRIBUTIONS TO THE ENERGY OPTIMIZATION OF AGRICULTURAL MACHINES FOR SEEDBED PREPARATION

4.1. General considerations

The system of agricultural machines used for soil cultivation, which prepares the seedbed, is considered a system, as shown in Figure 4.1 (Trendafilov, et al. 2023). The objective of optimization is to determine the optimal parameters of the seedbed preparation process. To optimize the seedbed preparation process, it is necessary to develop mathematical models that simulate the energy consumption of the components of the agricultural machinery system, which can be validated experimentally.

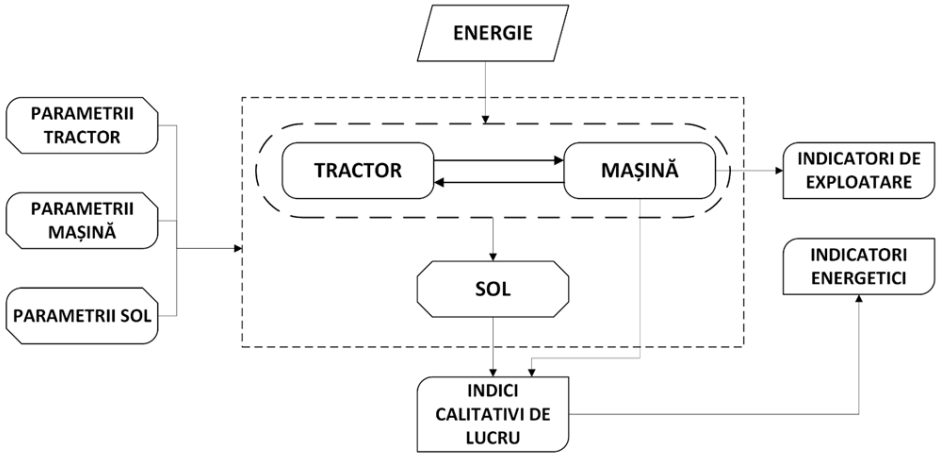


Figure 4.1. *Block diagram of the systemic representation for the mechanical soil processing process*

The system of agricultural machines used for soil tillage, which perform seedbed preparation, is considered a system, as shown in Figure 4.1 (Trendafilov et al. 2023). The objective of optimization is to determine the optimal parameters of the seedbed preparation process. For optimizing the seedbed preparation process, it is necessary to develop mathematical models that simulate the energy consumption of the components of the agricultural machinery system, which can be experimentally validated.

The draft resistance of agricultural machines, like other parameters of the aggregate, has a strongly random character. The variation characteristics are influenced by several factors, the most important being: soil type, soil compaction, moisture, unevenness, texture and structure of the tilled soil, as well as certain variations occurring at the driving wheels and at the articulation points of the aggregate. The influence of these factors is more pronounced in aggregates with powerful tractors and at high working speeds (Ciulu and Bârcă 2002).

The variation of working resistance of agricultural machines also leads to the unstable operation of the tractor engine. This variation, correlated with the engine load factor, causes power losses of up to 10–15%. The load regime of the machines within the aggregate results in random dynamic processes in all elements of the aggregate (Șandru 1983).

The random character of the engine torque, in turn, influences the traction characteristics of the tractor (Tecușan 1982). Its negative effect can be observed on the adhesion force and on the slip of the driving wheels. At equal traction forces, when the dispersion of their value is high, tractor slippage increases. As working speed increases, the working resistance of agricultural machines also increases.

It is imperative to determine the optimal operating parameters of agricultural aggregates for seedbed preparation in order to ensure the full use of the tractor engine's power and to operate the aggregate at maximum working capacity, i.e., to achieve an optimal power balance (Dobrescu 1981, Lamarche 1991). At present, this can be achieved using analytical and numerical calculation algorithms, implementable on modern agricultural tractors.

Agricultural aggregates, under real working conditions, are used in the presence of influencing factors with a strongly random character. Consequently, most processes of agricultural aggregates under real conditions have a random character (Șandru 1983). These processes can be studied—abstracted—using the theory of random processes. Attempts to reproduce them under given conditions lead to different results. Therefore, only the probability of their occurrence can be predicted (Târcolea 1989).

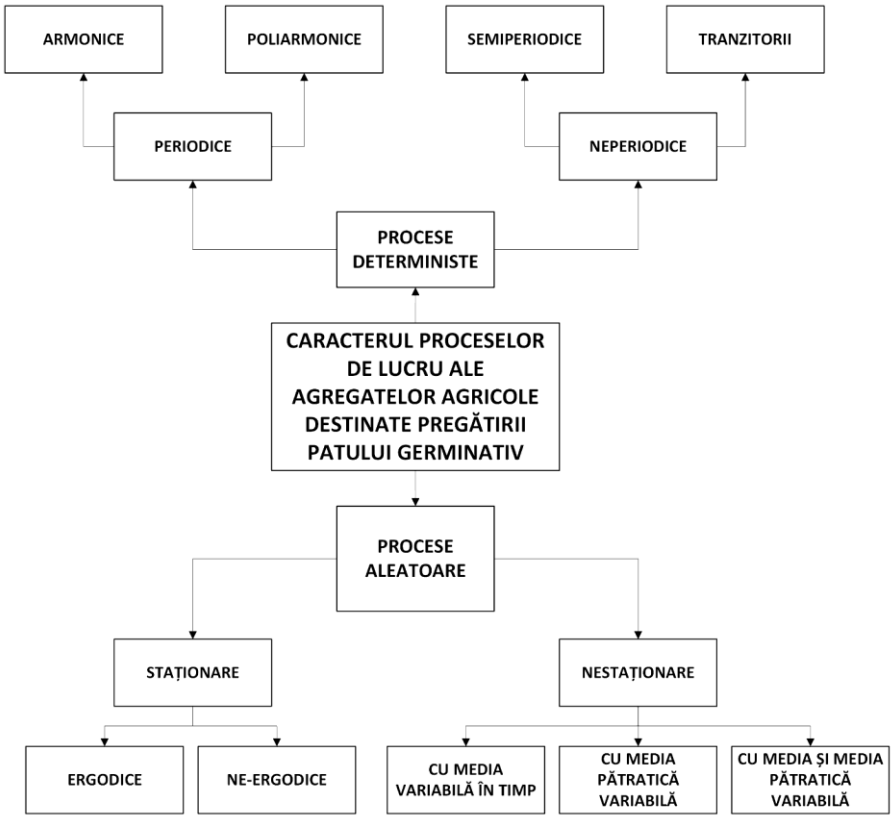


Figure 4.2. *The nature of the working processes of agricultural aggregates intended for seedbed preparation (Dobrescu 1981)*

Figure 4.2 shows a classification of both deterministic and random processes encountered in agricultural aggregates. Deterministic processes can be periodic or non-periodic. Periodic processes, in turn, can be harmonic or polyharmonic, while non-periodic ones are generally transient processes.

4.2. Operation of agricultural machines intended for seedbed preparation

The indicators for operating the agricultural system in seedbed preparation reflect the efficiency of its mode of operation. The analysis of these indicators is directly related to the study of the kinematics of the agricultural system (Şandru 1983).

The operating indicators of the agricultural system are numerical values that evaluate the working process and show the extent to which the machines comply with general technical standards (Boruz 2005, Ciulu and Bârcă 2002, Ciulu 2000, Koolen and Kuipers 1983, Marin 2011). The indicators for operating agricultural machines used for soil tillage are:

- work capacity;
- time utilization coefficients;
- specific path;
- work stroke coefficient.

4.3. Development of mathematical models for the energy consumption of seedbed preparation machines

The mathematical modeling of the energy performance of soil tillage machines consists in establishing the calculation relations for the energy components required for soil processing and analyzing them, with the aim of identifying methods to reduce energy consumption in seedbed preparation operations (Bodolan and Brătucu 2013, Şandru 1983).

4.3.1. Development of mathematical models for the energy consumption of deep soil loosening equipment

In the case of soil tillage using the subsoiler, energy is consumed for pulling the implement, cutting and displacing the soil portion, splitting the displaced soil, as well as covering the losses in the machine transmission, as follows (Brătucu 1999, Vlad 2013):

$$E_{subsoliere} = E_{deplasare} + E_{taiere,dislocare} + E_{despicare} + E_{pierderi} \quad [J] \qquad (4.1)$$

The specific mechanical work represents the energy required to displace a unit volume of soil. In the case of soil tillage using the subsoiler, the specific mechanical work is calculated by relating the mechanical work performed to the volume of soil displaced over a traveled distance, that is (Brătucu 2007):

$$L_{ss} = \frac{L_s}{V_{sol}} \quad [J] \qquad (4.2)$$

where: *Ls* – mechanical work performed by the subsoiler, measured in J; *Vsol* – volume of soil displaced by the subsoiler, measured in m³.

4.3.2. Development of mathematical models for the energy consumption of plows

In soil tillage with the plow, energy is used for pulling the implement, for cutting and detaching the soil slice, as well as for throwing it. The mathematical model for calculating the energy consumption of the plow is (Şandru 1983):

$$E_{arat} = f \cdot G_{plug} \cdot v_m \cdot t_{arat} + k \cdot a \cdot b \cdot v_m \cdot t_{arat} + \varepsilon \cdot a \cdot b \cdot v_m^3 \cdot t_{arat} + E_{pierderi} \quad [W] \quad (4.3)$$

Equation (4.3) defines the mathematical model of the energy consumption of the plow, providing useful data for optimizing machine parameters to minimize energy consumption.

The energy required for moving the machine, *Edeplasare*, is transformed into the mechanical work needed for pulling the machine and for soil deformation. This is directly proportional to the machine's weight *Gplug* and to the rolling resistance coefficient *f* between the depth adjustment wheel and the soil (Ciulu and Bârcă 2002):

$$E_{deplasare}=f(f,G_{plug}) \quad (4.4)$$

To reduce the energy required for pulling the plow, action is taken on its two main components. The machine's weight can be reduced already at the design stage by selecting lighter materials that are still resistant to mechanical stresses. The rolling resistance coefficient can be reduced by using wheels with the largest possible diameters and widths.

The energy required for the mechanical operations of plowing is used for cutting and displacing the furrows, lifting the displaced soil onto the moldboard surface, and throwing it sideways.

The energy required for cutting and displacing the furrows depends on the size of the displaced soil and is directly proportional to the working depth, the width of the moldboard, and the soil's physical-mechanical properties (Căproiu 1982):

$$E_{taiere}=f(a,b,k) \quad (4.5)$$

The energy required for throwing the soil slice depends on its dimensions, on the size and shape of the moldboard, as well as on the physical properties of the tilled soil (Krasnicenko 1963 and 1964).

$$E_{ridicare}=f(a,b,\varepsilon) \quad (4.6)$$

The specific cutting area represents a geometric parameter of the displaced soil slice. It is defined as the ratio between the cutting surface of the displaced soil, St, and its volume, V. It can be calculated using the equation (Vlad 2013):

$$S_{modelare} = \frac{S_t}{V} = \frac{(a+b)\cdot S}{a\cdot b\cdot S} = \frac{1}{b} + \frac{1}{a} \ [m^2/m^3] \quad (4.7)$$

where: S is the distance traveled by the machine, measured in m; a is the working depth, measured in m; b is the width of the plowshare, measured in m.

The specific mechanical work represents the energy required to displace a unit volume of soil. In the case of soil tillage using the plow, the specific mechanical work is calculated by relating the mechanical work performed over the traveled distance S to the volume of soil displaced over that distance, as follows (Ciulu and Bârcă 2002):

$$L_S = \frac{L_{arat}}{V_{sol}} = \frac{E_{arat}}{a\cdot b\cdot S} \quad [J/m^3] \quad (4.8)$$

where: L_{arat} – represents the mechanical work performed by the plow, measured in J; V_{sol} – represents the volume of soil displaced by the plow, measured in m³; *Earat* – represents the energy required to operate the plow, measured in J; S – represents the distance traveled by the machine during operation, measured in m.

For an aggregate consisting of a 180 HP tractor (A 1800-A) and a variable working width plow with 5 moldboards (PP5VM), designed to carry out plowing on flat land or slopes of up to 6° (Fig. 4.3), the power balance and the optimization algorithm of the aggregate's energy performance are presented below.



Figure 4.3. *Plowing aggregate consisting of a 180 HP tractor and a variable working width plow with 5 moldboards*

The main objective is to determine the optimal operating parameters of a plowing aggregate consisting of a 180 HP tractor and a 5-moldboard plow, namely: v – working speed and B – working width, which ensure the full utilization of the tractor engine's power and the use of the aggregate at its maximum working capacity. As can be seen below, the power balance equation can be used as the objective function for optimizing the power balance.

The aggregate requires power for movement and power for performing the plowing operation. The tractor's driving wheels develop the power needed to operate the aggregate. As a constraint, the travel time utilization coefficient τd can be considered, knowing that its level is proportional to the working capacity of the aggregate.

The power balance of a plowing aggregate can be expressed by the relation (Dobrescu 1981):

$$P_M \cdot \tau_M = \frac{f_1 \cdot G \cdot v + f_v \cdot G \cdot v^2}{\eta_T \cdot (1-\delta_p)} + \frac{k \cdot a \cdot B \cdot v + \varepsilon \cdot a \cdot B \cdot v^3}{\eta_T \cdot (1-\delta_p)} \tag{4.9}$$

where: PM – engine power, (W); ηM – engine power utilization coefficient; ηp – transmission efficiency at the power take-off and drive wheels; f_1 – proportionality coefficient; fv – coefficient of increased rolling resistance due to speed increase, (s/m); δp – tractor slippage; G – weight of the aggregate, (N); v – working speed, (m/s); B – working width, (m); a – working depth, (m); k – soil slice deformation and crumbling resistance, (N/m²); ε – coefficient characterizing the moldboard shape and soil properties, (N·s²/m⁴).

If it is considered that between the weight of the aggregate and the working width there is a relationship of the form $GB = \alpha \cdot B$, where α is the specific weight of the aggregate per working width, (N/m), the objective function becomes (Dobrescu 1981):

$$P_M \cdot \eta_M \cdot \eta_T \cdot (1-\delta_p) = f_1 \cdot \alpha \cdot B \cdot v + f_v \cdot \alpha \cdot B \cdot v^2 + k \cdot a \cdot B \cdot v + \varepsilon \cdot a \cdot B \cdot v^3 \tag{4.10}$$

The optimal parameters B and v are those that ensure maximum productivity at the engine power level. Since the technical productivity of plowing aggregates is linked to the level of the travel time utilization coefficient τd, this coefficient constitutes the constraint.:

$$\frac{v_g \cdot L}{v_g \cdot L + v \cdot (\Omega + m_1 \cdot B)} - \tau_d = 0 \tag{4.11}$$

The optimal solution can be found using the Lagrange multiplier:

$$\begin{cases} \frac{\partial P_M}{\partial v} + \lambda \cdot \frac{\partial \tau_d}{\partial v} = 0 \\ \frac{\partial P_M}{\partial B} + \lambda \cdot \frac{\partial \tau_d}{\partial B} = 0 \end{cases} \tag{4.12}$$

and the restrictions:

$$\frac{m}{m + v \cdot (\Omega + m_1 \cdot B)} - \tau_d = 0 \tag{4.13}$$

where m and m_1 are operating parameters dependent on the aggregate's no-load travel speed (v_g), the plot length (L), the no-load travel distance (S_g), and the plot width (C), ($m = v_g \cdot L$, $m_1 = Sg \cdot s/C$).

The terms in the system of equations (4.12) are determined as follows:

$$\frac{\partial P_M}{\partial v} = f_1 \cdot \alpha \cdot B + 2 \cdot f_v \cdot \alpha \cdot B \cdot v + k \cdot a \cdot B + 3 \cdot \varepsilon \cdot a \cdot B \cdot v^2 \tag{4.14}$$

$$\frac{\partial P_M}{\partial B} = f_1 \cdot \alpha \cdot v + f_v \cdot \alpha \cdot v^2 + k \cdot a \cdot v + \varepsilon \cdot a \cdot v^3 \tag{4.15}$$

$$\frac{\partial \tau_d}{\partial v} = \frac{m \cdot (\Omega + m_1 \cdot B)}{[m + v \cdot (\Omega + m_1 \cdot B)]^2} \tag{4.16}$$

$$\frac{\partial \tau_d}{\partial B} = \frac{m_1 \cdot m \cdot v}{[m + v \cdot (\Omega + m_1 \cdot B)]^2} \tag{4.17}$$

A system of three equations with three unknowns is obtained:

$$\begin{cases} f_1 \cdot \alpha \cdot B + 2 \cdot f_v \cdot \alpha \cdot B \cdot v + k \cdot a \cdot B + 3 \cdot \varepsilon \cdot a \cdot B \cdot v^2 - \lambda \cdot \frac{m \cdot (\Omega + m_1 \cdot B)}{[m + v \cdot (\Omega + m_1 \cdot B)]^2} = 0 \\ f_1 \cdot \alpha \cdot v + f_v \cdot \alpha \cdot v^2 + k \cdot a \cdot v + \varepsilon \cdot a \cdot v^3 - \lambda \cdot \frac{m_1 \cdot m \cdot v}{[m + v \cdot (\Omega + m_1 \cdot B)]^2} = 0 \\ \frac{m}{m + v \cdot (\Omega + m_1 \cdot B)} - \tau_d = 0 \end{cases} \tag{4.18}$$

The variable λ is eliminated by equating its value from the first equation of system (4.18) with the value obtained from the second equation, resulting in::

$$3\cdot v^2+2\cdot v\cdot\left[\frac{m\cdot(1-\tau_d)}{\tau_d\cdot\Omega}-\frac{\alpha\cdot f_v}{\varepsilon\cdot a}\right]+\frac{f_1\cdot(f_v\cdot\alpha+k\cdot a\cdot\Omega)}{\varepsilon\cdot\alpha\cdot\Omega}=0 \quad (4.19)$$

where:

$$v_{opt}=\frac{1}{3}\cdot\left[\frac{m\cdot(1-\tau_d)}{\tau_d\cdot\Omega}-\frac{\alpha\cdot f_v}{\varepsilon\cdot a}+\sqrt{\left(\frac{\alpha\cdot f_v}{\varepsilon\cdot a}\right)^2+\left(\frac{m\cdot(1-\tau_d)}{\tau_d\cdot\Omega}\right)^2+\frac{\alpha\cdot f_v\cdot m\cdot(1-\tau_d)}{\varepsilon\cdot a\cdot\tau_d\cdot\Omega}-\frac{3\cdot(\alpha\cdot f_1+k\cdot a)}{\varepsilon\cdot a}}\right] \quad (4.20)$$

From the third equation of system (4.18), it follows::

$$B_{opt}=\frac{m\cdot(1-\tau_d)-\tau_d\cdot\Omega\cdot v_{opt}}{\tau_d\cdot m_1\cdot v_{opt}} \quad (4.21)$$

The productivity of the aggregate is:

$$U_{\tau_d}=v_{opt}\cdot B_{opt}\cdot\tau_d \quad (4.22)$$

The power required to operate the aggregate is calculated using the relation (Dobrescu 1981):

$$P_{min}=f_1\cdot\alpha\cdot B_{opt}\cdot v_{opt}+f_v\cdot v^2\cdot\alpha\cdot B_{opt}+B_{opt}\cdot v_{opt}\cdot a\cdot k+\varepsilon\cdot a\cdot B_{opt}\cdot v_{opt}^3 \quad (4.23)$$

```python
import numpy as np
import matplotlib.pyplot as plt

m_1 = 45
m = 700
omega = 40

tau_d_values = [0.7, 0.71, 0.72, 0.73, 0.74, 0.75, 0.76, 0.77, 0.78]

v_opt = np.linspace(0.5, 2.5, 100)

plt.figure(figsize=(8, 6))

for tau_d in tau_d_values:
    B_opt = (m * (1 - tau_d) - tau_d * omega * v_opt) / (tau_d * m_1 * v_opt)
    # Filtrare pentru valorile B_opt în intervalul [0,8, 2]
    mask = (B_opt >= 0.8) & (B_opt <= 2)
    plt.plot(v_opt[mask], B_opt[mask], label=f"$\\tau_d = {tau_d}$")

plt.title("Graph of $B_{opt}$ vs $v_{opt}$ for Different $\\tau_d$")
plt.xlabel("$v_{opt}$ (m/s)")
plt.ylabel("$B_{opt}$ (m)")
plt.ylim(0.8, 2)
plt.axhline(0, color='black', linewidth=0.8, linestyle='--')
plt.legend()
plt.grid()

plt.show()
```

a)

```python
%matplotlib notebook

import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

m_1 = 45
m = 700
omega = 40

v_opt_values = np.linspace(0.5, 2.5, 50)  # v_opt între 0.5 și 2.5
tau_d_values = np.linspace(0.7, 0.9, 50)    # tau_d între 0.7 și 0.9

V_OPT, TAU_D = np.meshgrid(v_opt_values, tau_d_values)

B_OPT = (m * (1 - TAU_D) - TAU_D * omega * V_OPT) / (TAU_D * m_1 * V_OPT)

mask = (B_OPT >= 1) & (B_OPT <= 2)

fig = plt.figure(figsize=(10, 7))
ax = fig.add_subplot(111, projection='3d')

sc = ax.scatter(V_OPT[mask], TAU_D[mask], B_OPT[mask], c=B_OPT[mask], cmap='viridis', marker='o')

cbar = fig.colorbar(sc, ax=ax, shrink=0.5, aspect=10)
cbar.set_label("$B_{opt}$ (m)")

ax.set_title("3D Plot of $B_{opt}$ as function of $v_{opt}$ and $\\tau_d$")
ax.set_xlabel("$v_{opt}$ (m/s)")
ax.set_ylabel("$\\tau_d$")
ax.set_zlabel("$B_{opt}$ (m)")

ax.zaxis.label.set_rotation(90)

ax.view_init(elev=30, azim=140)  # ROTIRE PENTRU VIZUALIZARE DIFERITĂ

plt.tight_layout()

plt.show()
```

b)

Figure 4.4. *Python code for determining the optimal working width of a 5-moldboard plow trupițe*

The power required for pulling the plow during the plowing process is calculated as follows (Gill and Vanden Berg 1968):

$$P_t = k_0 \cdot a \cdot B_l \cdot v_l \quad [\text{W}] \quad (4.24)$$

where *vl* – represents the working speed of the plowing aggregate [m/s]. The energy consumption per unit of worked area is calculated using the relation:

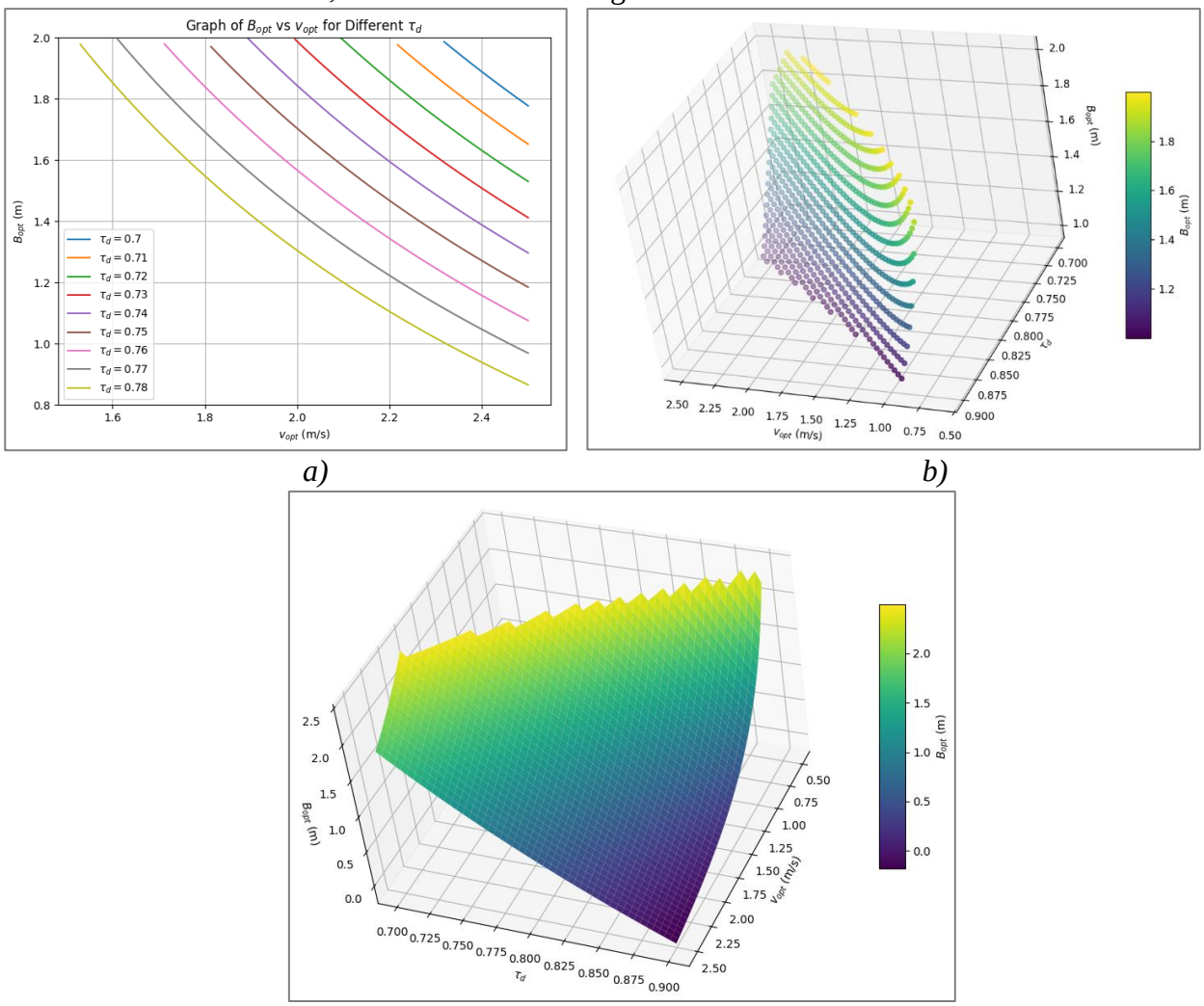
$$E_{ha} = \frac{P_t}{S_h} \quad [\text{Wh/ha}] \quad (4.25)$$

where S_h – represents the working capacity of the plowing aggregate [ha/h]. By classical analytical calculation, applying the developed mathematical models, for a plowing aggregate operating under the conditions given in the first column of Table 4.1, the optimal parameters obtained are presented in the second column of the same table..

Table 4.1. *Parameters resulting from the calculation for a plowing aggregate*

Conditions for a plowing aggregate consisting of the A-1800 A tractor and the PSP-5 (35) plow	Parameters of the plowing aggregate resulting from the calculation
Tractorului mass: G_t*=97000 N* *Plough mass:* G_p*=30000 N* *Agregate mass:* $G=G_t+G_p=127000$ *N* $\tau_d=0.9$; $\Omega=40$; $m_1=10$; $k=35000$ *N/m*^{2}; $f_1=0.1$ $f_v=0.09$; $L=1000$ *m*; $v_g=0.5$ *m/s*; $a=0.25$ *m* $\varepsilon=3000$ N·s^2/m^4	**v_{opt}=2.03 m/s** **B_{opt}=1.5 m**

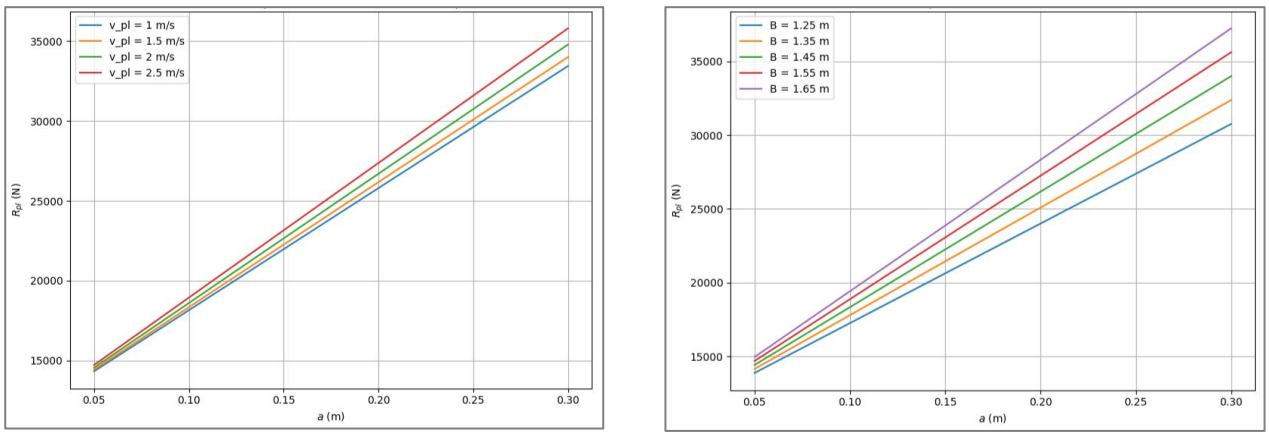
Using the calculation algorithms developed in Chapter 3 and the Python codes created, the optimal values for the total working width of the plow were computed and plotted (Fig. 4.5.a), as well as the 3D representation of its dependence on working speed and on the travel time utilization coefficient (τd) (Fig. 4.5.b). In addition, Fig. 4.5.c presents the 3D graph of the dependence of the optimal working width on the working speed, with values in the range 0.5–2.5 m/s, and on the travel time utilization coefficient, with values in the range 0.7–0.9.



a) *b)*

c)

Figure 4.5. *Graphical representation of the dependence of the optimal plowing width on the working speed and the travel time utilization coefficient for a 5-moldboard plow*



a) *b)*

Figure 4.6. *Graphical representation of the dependence of the draft force of a 5-moldboard plow on working depth for different working speeds and different total working widths*

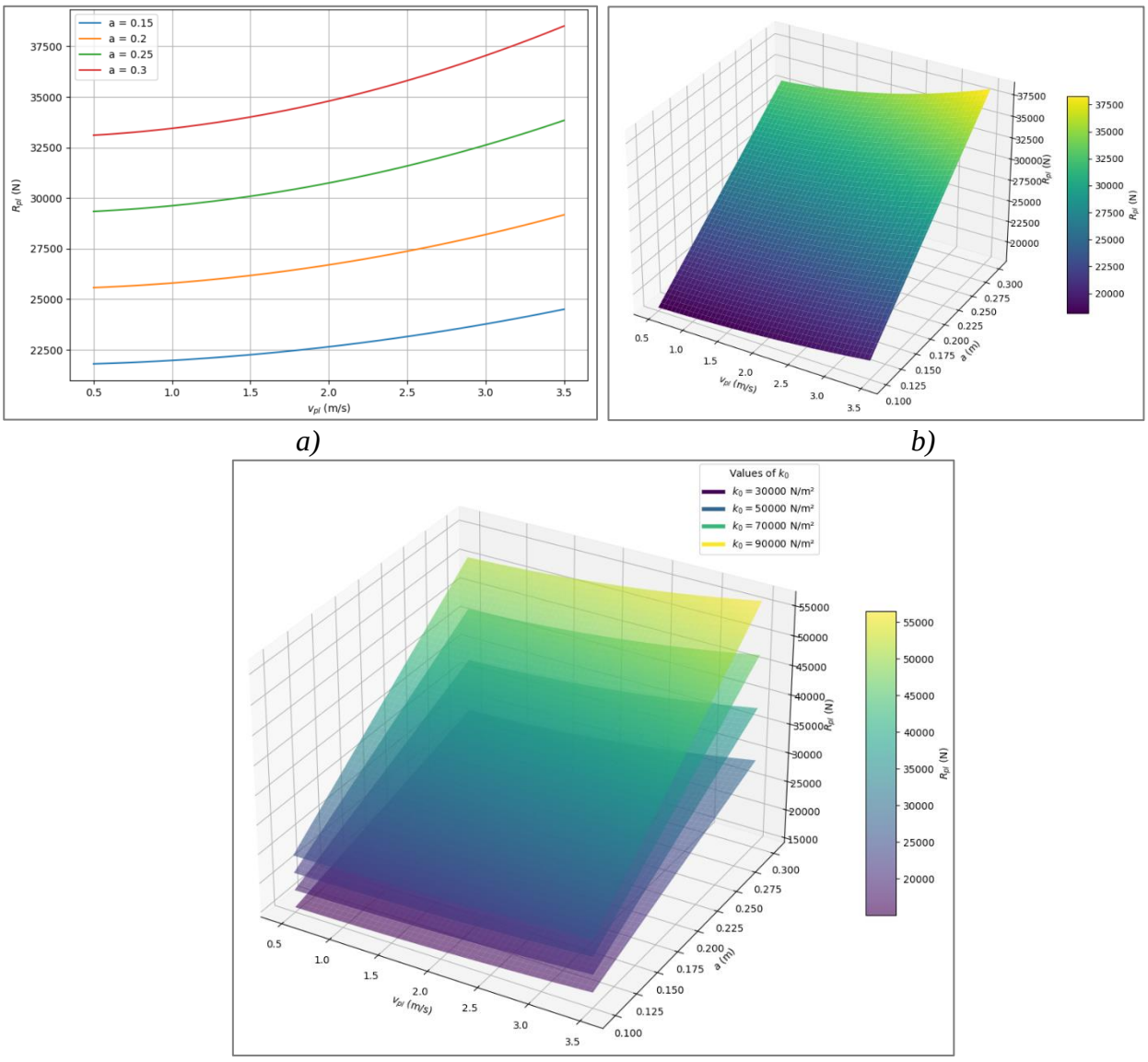


Figure 4.7. *Graphical representation of the dependence of the draft force of a 5-moldboard plow on working speed at different operating depths and various working widths*

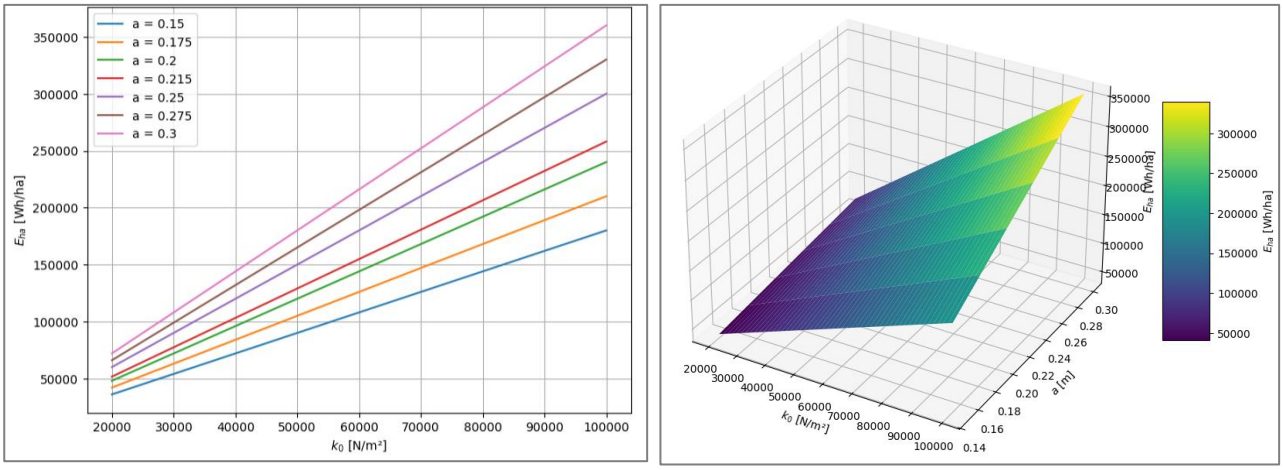


Figure 4.8. *Graphical representation of the dependence of the draft force of a 5-bottom plow on the working speed at different operating depths and various working widths.*

The optimal operation of plowing aggregates is essential for achieving efficient resource use and cost reduction. Fully utilizing the tractor engine power and operating the plow aggregate at maximum working capacity enables the realization of an optimal power balance. The optimal operating regime can be determined using numerical calculation algorithms, based on Lagrange multipliers (subchapter 3.6.2), with the aid of computational programs (Python code). To achieve maximum productivity at the engine power level, it is necessary to calculate the optimal working speed and optimal working width as a function of the utilization coefficient of the plowing aggregate's travel time.

4.3.3. Development of mathematical models for the energy consumption of soil leveling equipment

The energy consumed in soil processing using the leveler is required for machine displacement, cutting and dislocating the soil slice, lifting the dislocated soil, moving the driving prism, and covering the transmission losses of the machine. The total energy required to operate the levelers can be calculated using the equation (Constantinescu 2005):

$$E_{nivelare} = E_{deplasare} + E_{taiere} + E_{ridicare} + E_{prisma} + E_{pierderi} \quad [J] \qquad (4.26)$$

The specific mechanical work represents the amount of mechanical work required to dislodge a unit volume of soil. In the case of soil processing using the leveler, the specific mechanical work is calculated by relating the mechanical work performed over the traveled distance (S) to the volume of soil dislodged over this distance, as follows (Brătucu 2010*)*:

$$L_s = \frac{L_n}{V_{sol}} = \frac{P_{niv} \cdot \tau}{a \cdot B \cdot S} \quad [J/m^3] \qquad (4.27)$$

where: L_n – represents the mechanical work performed by the leveler, measured in J; V_{sol} – represents the volume of soil dislodged by the leveler, measured in m3; P_{niv} – represents the power required to operate the leveler, measured in W; τ – represents the leveling time, measured in s; S – represents the distance traveled during leveling, measured in m.

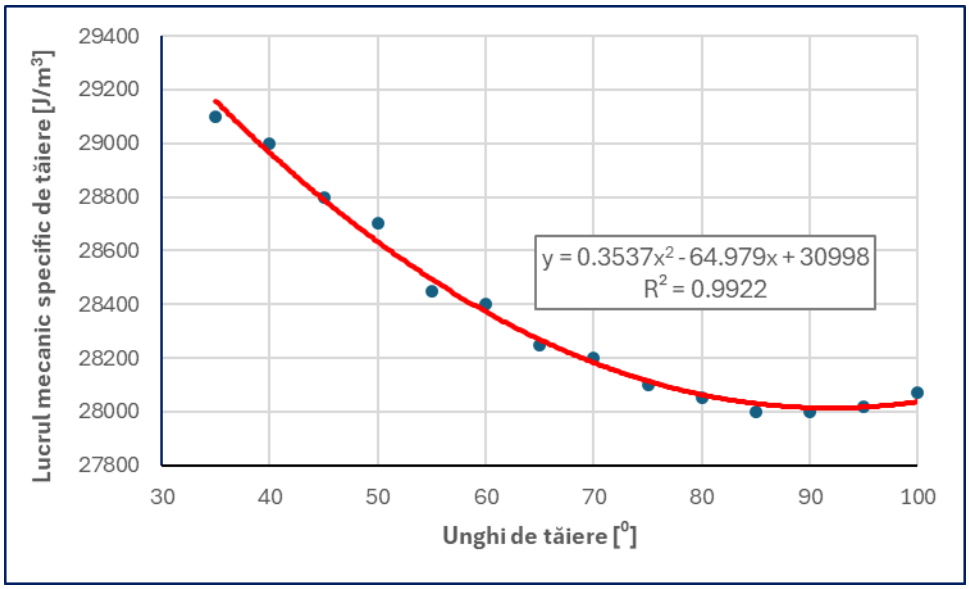


Figure 4.9. *Dependence of the specific mechanical work on the blade cutting angle during leveling (Vlad 2013)*

The empirical relation resulting from figure 4.9, which establishes the connection between the specific mechanical work of soil tillage with the leveler and the blade cutting angle, is: $L = 0.3537 \cdot \alpha^2 - 64.979 \cdot \alpha + 30998 \quad [J/m^3]$ (4.28)

Figure 4.10 illustrates the variation of the specific mechanical work considering the working depth of the leveler, and equation (4.29) presents the empirical relation of this dependency: $L = 22.571 \cdot a^2 - 1027.1 \cdot a + 36440 \quad [J/m^3]$ (4.29)

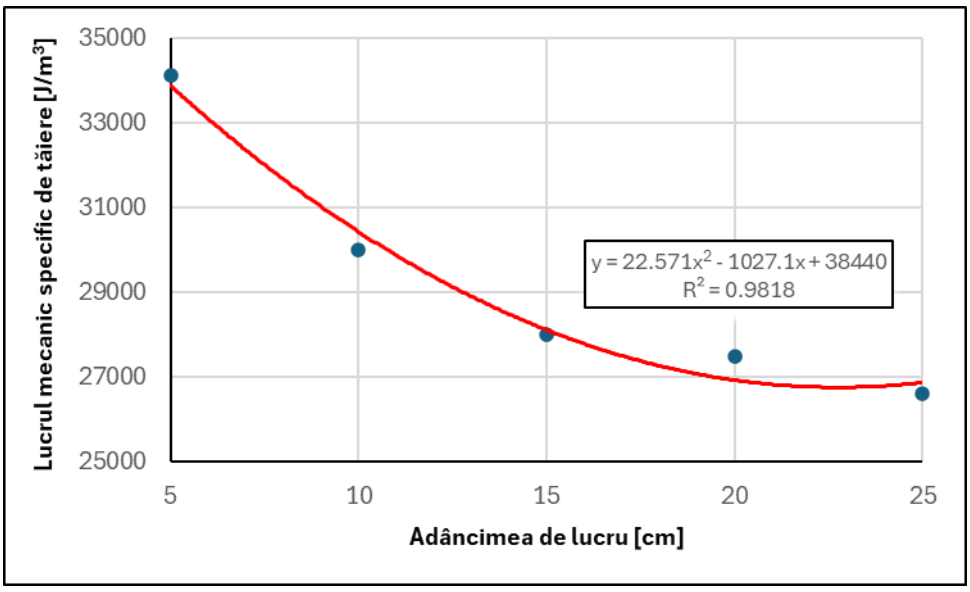


Figure 4.10. *Dependence of the specific mechanical work on the operating depth in leveling (Ciulu and Bârcă 2002)*

According to relation (4.29) and the diagram presented for the specific working conditions, it is observed that as the working depth increases, the specific mechanical work required for soil processing with the leveler decreases. Moreover, adjusting the blade cutting angle to values close to 90° contributes to reducing the specific mechanical work of the operation. Thus, the use of the leveler is more efficient at greater depths.

4.3.4. Mathematical modeling of the energy consumption of disc harrows

During the working process of the 4×2 tractor (U-650) (Fig. 4.11), the following forces act: the tractor weight G, the resultant force due to inertia R_i rez, the rolling resistance force R_r, the rolling resistance moments M_r1 and M_r2, the driving force F_m, the components F_t and R_z of the resultant force R transmitted to the tractor by the implement, and the reactions Z_1 and Z_2 at the two axles (front and rear). It is considered that the tractor weight G is applied at its center of mass, defined by the coordinates a_c and h. The action of the implement on the 4×2 tractor can be replaced by the implement's draft resistance force (parallel to the soil surface) F_t and by the component normal to the soil surface R_z. The point of application of these two forces is defined by the coordinates l_t (with respect to the rear axle axis) and h_t (with respect to the soil surface).

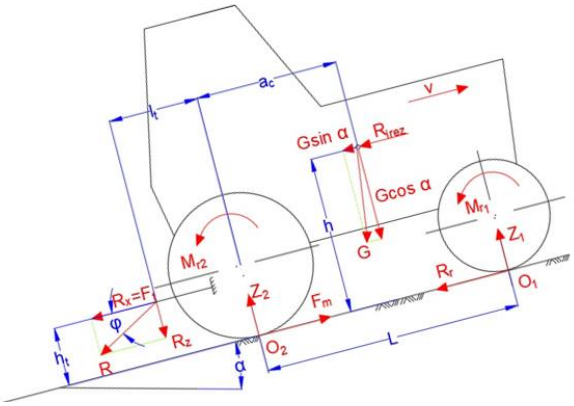


Figure 4.11. *Forces acting on a 4×2 tractor coupled with a trailed or semi-mounted implement (Şandru 1983)*

In the case of the aggregate formed by a 4×2 tractor and a semi-mounted disc harrow (Fig. 4.12), the reactions Z_1 and Z_2 are determined based on the equilibrium equations of the tractor under the action of external forces, using the following relations (Şandru 1983):

$$\begin{cases} Z_1 = [G \cdot a_c \cdot \cos\alpha - (G \cdot \sin\alpha + R_{irez}) \cdot h - F_t \cdot h_t - R_z \cdot l_t - M_r]/L \\ Z_2 = [G \cdot (L - a_c) \cdot \cos\alpha + (G \cdot \sin\alpha + R_{irez}) \cdot h + F_t \cdot h_t + R_z \cdot (L + l_t) + M_r]/L \end{cases} \quad (4.30)$$

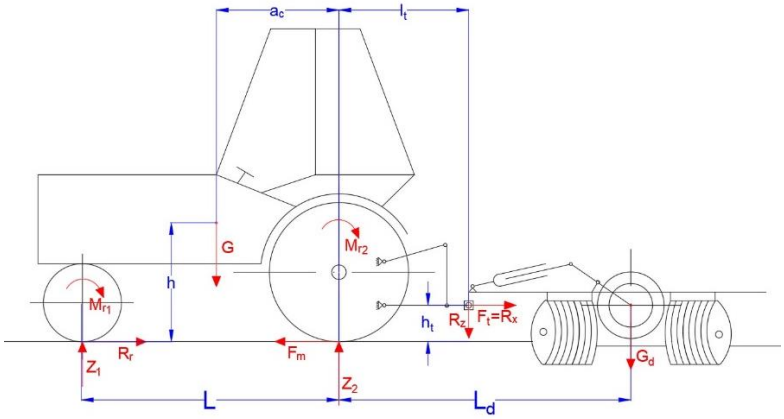


Figure. 4.12. *Forces acting on a 4×2 tractor coupled with a semi-mounted disc harrow during operation*

The total load ZtZ_tZt acting on the tractor axles is given by the sum of the reactions on the two axles, namely:

$$Z_t = Z_1 + Z_2 = G \cdot \cos\alpha + R_z \quad (4.31)$$

The expression of the rolling resistance moment MrM_rMr in the system of equations (4.73) is determined as the sum of the rolling resistance moments on the two axles.:

$$M_r = M_{r1} + M_{r2} = f_{r1} \cdot Z_1 + f_{r2} \cdot Z_2 \cong f_{r2} \cdot (Z_1 + Z_2) = f_{r2} \cdot Z_t = r_2 \cdot R_r \quad (4.32)$$

in which R_r is the total rolling resistance of the tractor::

$$R_r = f \cdot Z_t \quad (4.33)$$

If the moment MrM_rMr, which has small values, is neglected and considering that the tractor moves on flat terrain at a constant speed, the calculation of the reactions Z_1, Z_2 and Z_t is done using the relations:

$$Z_1 = \frac{G \cdot a_c}{L} - \frac{F_t \cdot h_t + R_z \cdot l_t}{L} \quad (4.34)$$

$$Z_2 = \frac{G \cdot (L - a_c)}{L} + \frac{F_t \cdot h_t + R_z \cdot (L + l_t)}{L} \quad (4.35)$$

$$Z_t = Z_1 + Z_2 = G + R_z \quad (4.36)$$

In the case of an aggregate consisting of a 4x2 tractor (U-650) and a mounted disc harrow (Fig. 4.13), during the working process on flat terrain, the normal reactions on the two axles of the tractor and the total load are calculated using the relations:

$$Z_1 = \frac{G \cdot a_c}{L} - \frac{G_d \cdot l_m + F_z \cdot l_r - F_x \cdot h_r}{L} \quad (4.37)$$

$$Z_2 = \frac{G \cdot (L - a_c)}{L} + \frac{G_d \cdot (L + l_m) + F_z \cdot (L + l_r) - F_x \cdot h_r}{L} \quad (4.38)$$

$$Z_t = Z_1 + Z_2 = G + G_d + F_z \quad (4.39)$$

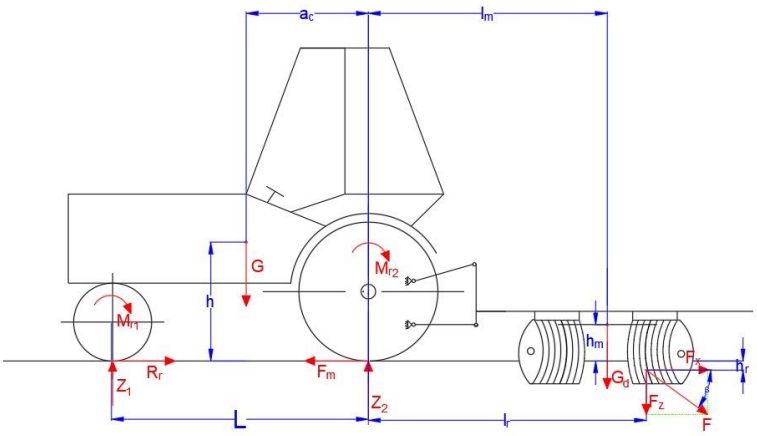


Figure 4.13. *Forces acting on a 4x2 tractor coupled with a mounted disc harrow during operation*

The traction balance equation of a tractor coupled with an agricultural machine during operation on flat land is (Năstăsoiu 1983):

$$F_t = F_m - R_r \quad (4.40)$$

where F_m represents the driving force (the tangential traction force), R_r the rolling resistance force, and F_t the traction force.

For the plowed surface on which the tractor operates in aggregate with the disc harrow, the coefficient of utilization of the adhesive weight is φm = 0.4 ÷ 0.6. Therefore, the expression of the driving force as a function of the vertical load on the drive axle results in:

$$F_m = \varphi_m \cdot Z_m \quad (4.41)$$

The rolling resistance force of the agricultural tractor is calculated using the relation:

$$R_r = f \cdot (Z_1 + Z_2) \quad (4.42)$$

in which: fff represents the rolling resistance coefficient of the tractor (f=0.12–0.14,f = 0.12–0.14,f=0.12–0.14 for settled plowed land), and Z_1 and Z_2 are the reactions on the two axles (front and rear).

The reactions Z_1 and Z_2 depend on the tractor weight G, the weight of the disc harrow G_d, the coordinates of the centers of gravity of the tractor and of the disc harrow, the wheelbase of the tractor, as well as the traction force F_t.

The slippage of the driving wheels depends on the magnitude of the traction force F_t, the load on the driving wheel Z_m, the type and condition of the running surface, and the shape and dimensions of the tire.

Figure 4.14 shows the slippage characteristic of the U-650 tractor on plowed land, for which a regression equation was derived using a second-degree interpolation function that establishes the dependence of wheel slippage on the traction force.

For the proper operation of the tractor–implement aggregate, it is recommended that the slippage of the driving wheels be kept within the range of 10–20% (Tecușan 1982). Therefore, as shown in Figure 4.18, for the U-650 tractor on plowed land, the traction force has recommended values in the range of 8.3–10.6 kN.

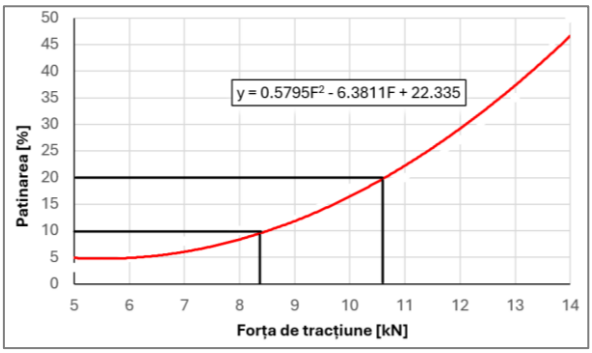


Figure 4.14. *Slippage characteristic of the U-650 tractor on plowed land (Tecușan 1982)*

To move the agricultural machine (in this case, the semi-mounted disc harrow), the value of the tractor's traction force must be greater than the resistance force resulting from the working process of the harrow, which can be calculated using the relation (Șandru 1983, Năstăsoiu 1983:

$$R_x = K_s \cdot B_l \tag{4.43}$$

in which: K_s represents the specific resistance per unit working width in soil tillage using the disc harrow (N/m); B_l is the working width of the disc harrow (m). For smooth disc harrows, the specific resistance has values of Ks=2÷3.25 kN (Năstăsoiu 1983). In the case of mounted disc harrows, the specific resistance KsK_sKs is 15–20% lower compared to that of trailed or semi-mounted implements (Năstăsoiu 1983).

Considering the importance of specific resistance per unit working width in soil tillage using the semi-mounted disc harrow, and the fact that this decreases by 20% in the case of the mounted harrow (Năstăsoiu 1983), a Python code was developed to calculate and plot the comparative variation curves of the resistant force RxR_xRx for the two coupling variants of the disc harrow (semi-mounted – blue curve and mounted – orange curve), as a function of KsK_sKs (Figure 4.15).

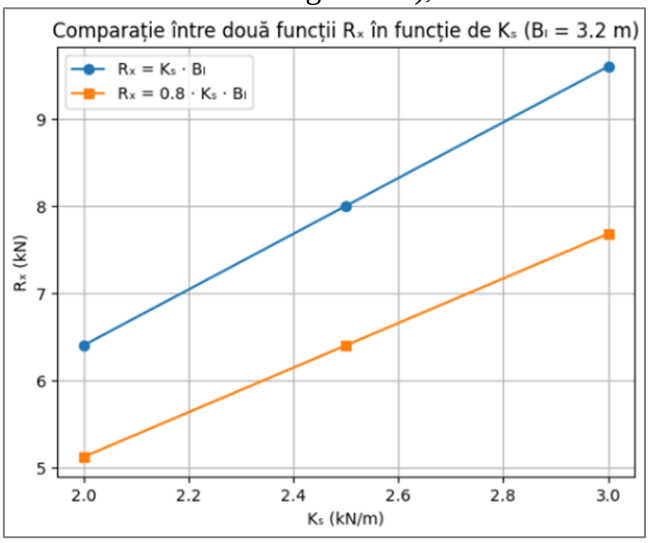


Figure 4.15. *Variația forței rezistente R_x în funcție de K_s*

Based on relations (4.34), (4.35), (4.37), and (4.38), a Python code was developed that allows the calculation of normal reactions on the two axles of the U-650 tractor, in the case of the two variants of disc harrow coupling: semi-mounted (Z_{11} and Z_{12}), mounted (Z_{21} and Z_{22}), and the figures below show the graphical variation of these reactions as a function of the specific resistance per unit working width when tilling the soil using the Ks disc harrow.

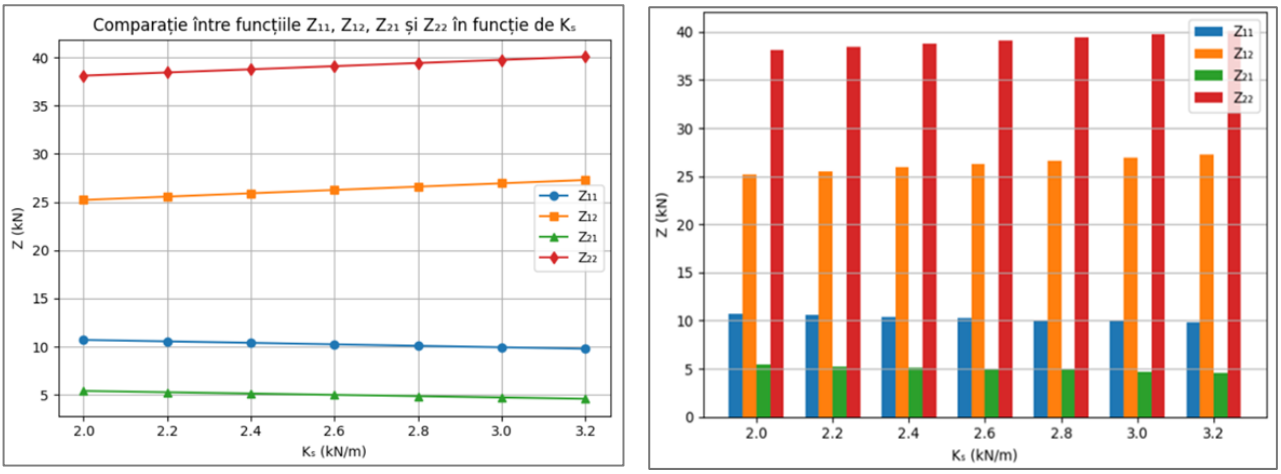


Figure 4.16. *Variation of normal reactions on the two axles of the U-650 tractor as a function of Ks*

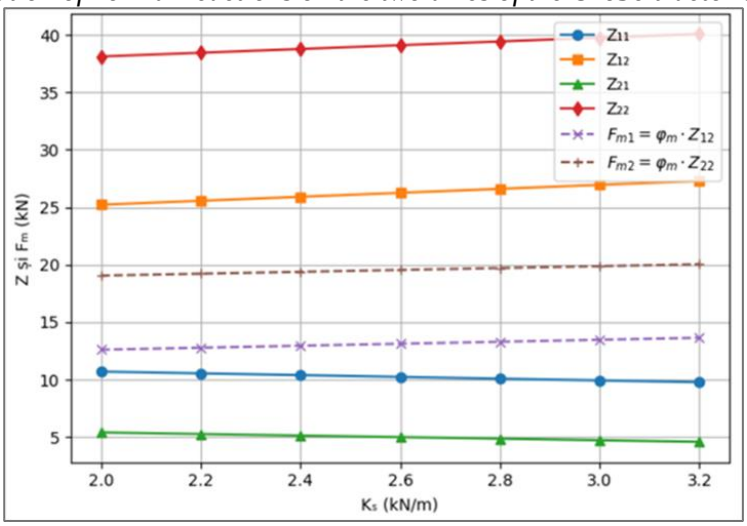


Figure 4.17. *Variation of normal reactions and driving force of the U-650 tractor as a function of Ks*

Pentru calculul forței de tracțiune a tractorului U-650 în agregat cu o grapă cu discuri semipurtată, respectiv în agregat cu o grapă cu discuri tractată, în funcție de condițiile solului și de secțiunea în plan transversal a brazdei de sol prelucrate la o trecere, precum și pentru trasarea grafică comparativă, s-a realizat un cod Python, iar reprezentarea grafică este ilustrată în figura 4.18.

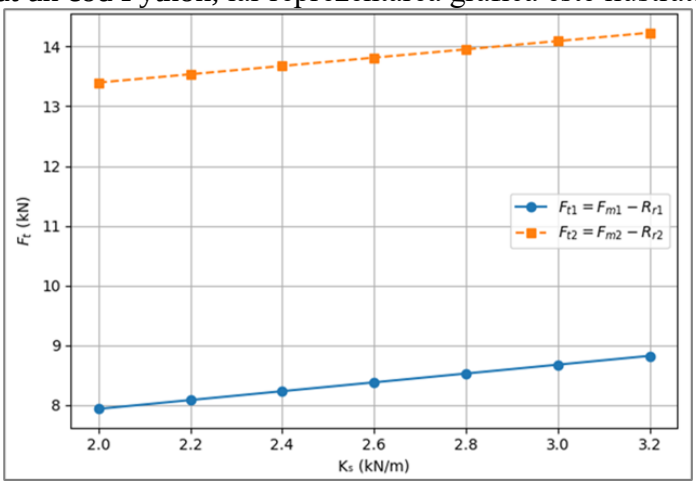


Figure 4.18. *Variation in the traction force of the U-650 tractor depending on K_s for the two variants of disc harrow coupling (semi-mounted F_{t1} and mounted F_{t2})*

From the experimental trials carried out, which will be presented in the next chapter, a reduction in fuel consumption of 11–14% was observed when the disc harrow was coupled in the mounted variant.

Chapter 5 EXPERIMENTAL RESEARCH ON DETERMINING THE OPTIMAL OPERATING REGIME OF AGRICULTURAL MACHINES FOR SEEDBED PREPARATION5.1. CONSIDERAȚII GENERALE PRIVIND CERCETAREA EXPERIMENTALĂ

Experimental research involves measuring certain mechanical, physical, or other types of quantities using appropriate measuring equipment and instruments. The main statistical indicators are determined, including: variance, sum of squared deviations, arithmetic mean, standard deviation, and coefficient of variation (Rus 1987, CIGR Handbook of Agricultural Engineering 1999, Rumșiski 1974, Păunescu and David 1999, Md-Tahir et al. 2021).

5.2. Objectives of the experimental research

The main purpose of the experimental research presented in this doctoral thesis was the optimization of energy consumption within the equipment and operations used for seedbed preparation in field crops, as well as the experimental validation of the developed calculation algorithms.

To achieve the main objective of the experimental research, a series of steps were necessary, along with solving several secondary objectives, namely:

- Correct and concrete selection of the object of experimental research;
- Establishing a rigorous methodology for studying the energy consumption of machinery used in seedbed preparation, thus ensuring the validity of the results obtained within the theoretical research;
- Monitoring the physical and physico-mechanical characteristics of the studied soils;
- Determining exploitation indicators of the equipment used for seedbed preparation;
- Calculating energy indicators of the equipment used in the seedbed preparation process;
- Measuring quality indices specific to seedbed preparation operations;
- Comparing theoretical energy indicators with those determined experimentally.

5.3. Methodology of the experimental research

Based on a detailed theoretical study of the energy requirements of the seedbed preparation process, mathematical models were developed to establish the interdependence between various parameters of the technical processes involved and the energy consumption of seedbed preparation technology.The mathematical model of total energy consumption is developed using the dynamic model of the agricultural system illustrated in Figure 5.1. It consists of a series of equations that highlight how the variables of the system interact with each other.

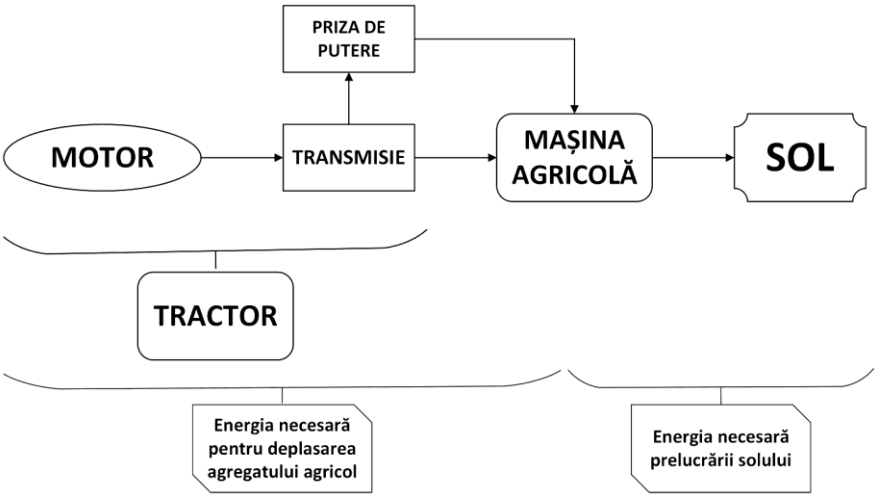


Figure 5.1. *The dynamic and energy model of the agricultural aggregate (Vlad 2013)*

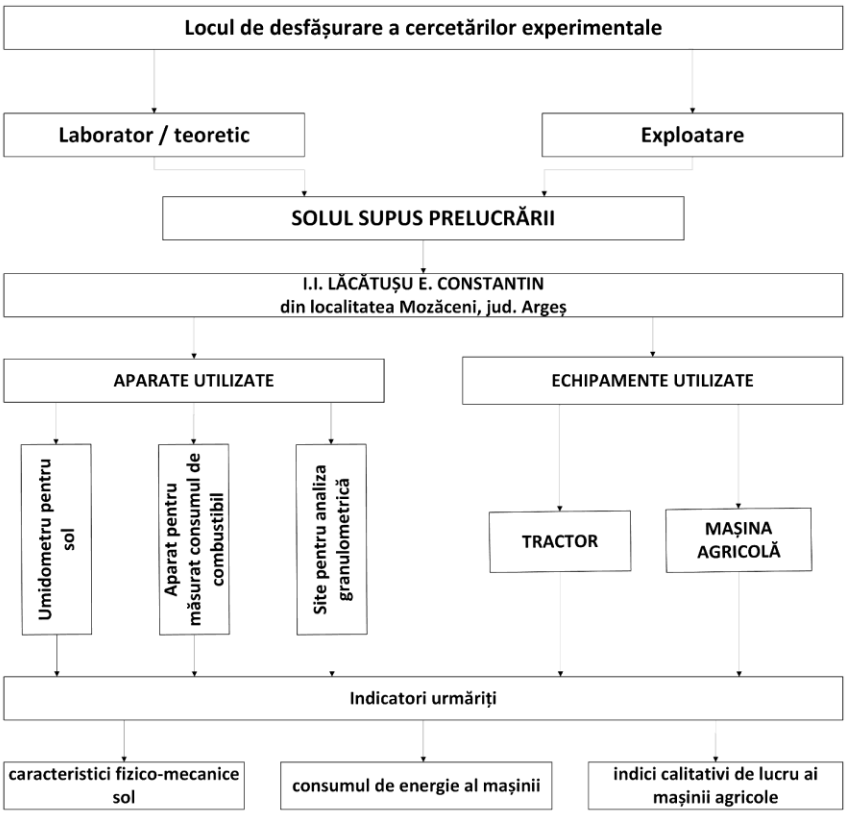


Figure 5.2. *The dynamic and energy model of the agricultural aggregate (Vlad 2013)*

To achieve the objectives of the experimental research, a general methodology was developed and implemented, which is illustrated in Figure 5.2.

5.4. Installation of measuring equipment on the tractor

To ensure the accuracy of the experiments, the measuring devices and equipment were tested in an accredited laboratory. The validity period indicated on their labels was also verified. The devices used in the experimental determinations were:

• the device used to measure fuel consumption;

• the devices used to measure the physical and mechanical characteristics of the soils studied, such as: the set of granulometric sieves; the moisture meter, etc.

• devices used to measure the quality indices of the germinative bed preparation works..



Figure 5.3. EDM 1404 fuel consumption measurement device

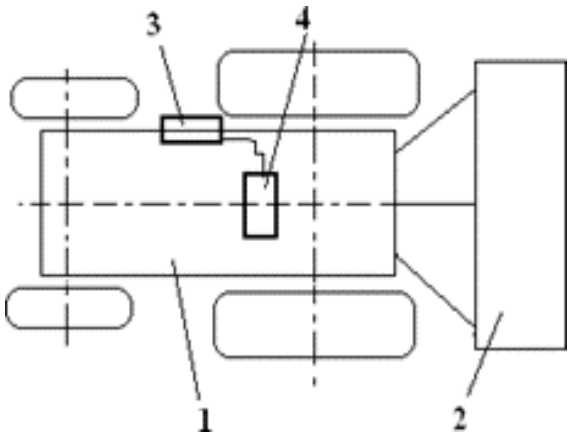


Figure 5.4. Installation diagram of measurement equipment on a tractor (Vlad 2013)

5.5. Experimental research on determining the optimal working process of plows

Plowing aggregates rank first in terms of energy consumption in plant cultivation technologies, accounting for approximately 30-35% of total diesel consumption (Şandru 1983). The energy efficiency of the plowing process is influenced by factors related to the design of the tractor and plow, environmental conditions, the physical and mechanical properties of the soil, and the operating modes chosen (Gill and Vanden Berg 1968, Căproiu Şt. 1982, Şandru 1983). Some of these factors are objective and cannot be modified at will during operation, while others have insignificant influences, but there are many characteristics of the aggregate that can and must be chosen appropriately to achieve an optimal energy balance (Dobrescu 1981, Upadhyay and Raheman 2020)..

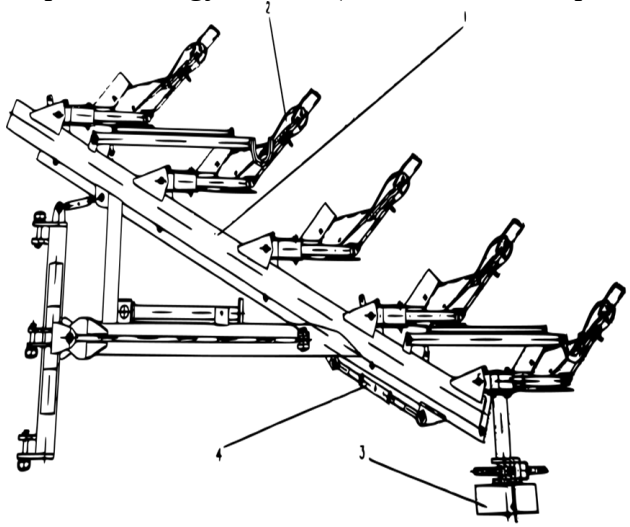


Figure 5.5. *Variable working width mounted plow for high-power tractor PP5VM (S.C. MAT S.A. 1987)*

For plowing, a variable working width mounted plow for high-power tractors (Figure 5.5) was used, which is designed to plow flat or sloping land with a gradient of up to 6°, on all types of soil, at a maximum working depth of 30 cm. The plow works in combination with 180-240 HP wheeled tractors equipped with a category III SR ISO 730-1+C1 suspension mechanism.

Tests under operating conditions of the plowing unit consisting of the A 1800-A tractor and the PP5VM plow were carried out between November 15, 2021, and December 10, 2021. The tests on the PP5VM variable-width five-body plow were carried out in accordance with the specific test procedures PSpl-01.00.32 "Testing of mouldboard plows" and PSpl-01.00.33 "Determination of energy indices for agricultural aggregates." The field tests of the plow were carried out on the farmland owned by I.I. LĂCĂTUȘU E. CONSTANTIN in Mozăceni, Argeș County, in accordance with the specific test procedures in force.

To determine the quality indices in accordance with the procedures in force issued by INMA (INMA-DI 2008, INMA-DI 2008) (PSpl-01.00.32 and PSpl-01.00.33), the following measuring and control devices and equipment were used: mechanical stopwatch, measurement accuracy +/-0.1 seconds; 15 m tape measure, accuracy class 2; 2 m tape measure, accuracy class 2; fuel consumption meter, measurement range 0-480 ml; METTLER PM6000 electronic scale, measurement range 0-6 kg, measurement accuracy +/-0.1 g; mechanical scale, measuring range 0-150 kg; markers, stakes; set of sieves with circular holes of 100, 80, 50, 40, 20 mm; furrow meter; metric frame; capsules for moisture samples.

Test conditions Field tests were carried out under the following conditions:
soil type: reddish-brown with a loamy-clay texture; previous crop: mechanically harvested wheat, straw baled and transported immediately after harvesting; height of plant residues: 15 cm; mass of plant residues: 70 g/m²; soil moisture at a depth of 25-30 cm: 18%.

Table 5.1. *Qualitative indicators of plowing performed with the aggregate consisting of the A-1800A tractor and the PP5VM plow on reddish-brown soil with an average moisture content of 18% in the plowed layer*

Lățimea de lucru pe trupiță b_t(cm)	Viteza de lucru efectivă V_e(Km/h)	Adâncimea medie de lucru a_m(cm)	Abaterea maximă de la a_m $\pm\Delta_a$(cm)	Abaterea standard σ_a(cm)	Inconstanța adâncimii de lucru V_a(%)	Lățimea medie de lucru B_m(cm)	Abaterea standard σ_B(cm)	Inconstanța lățimii de lucru V_B(%)	Gradul de mărunțire a solului G_{ms}(%)	Gradul de acoperire al resturilor vegetale G_v(%)
30	8,04	19,7	2,4 3,6	1,88	6,65	156	11,8	5,49	85,8	85,6
	7,85	25,1	1,8 3,2	1,77	6,23	154	12,3	4,83	83,4	89,3
	7,38	29,7	1,7 2,9	1,73	5,95	153	11,5	4,39	80,2	93,4
35	7,87	20,1	2,1 3,2	1,85	6,53	186	10,9	5,93	84,3	88,6
	7,45	24,9	1,8 3,1	1,79	6,11	182	11,2	5,22	82,4	91,5
	6,83	30,2	2,2 3,3	1,76	5,84	181	10,5	4,11	80,3	94,3
40	7,42	19,9	2,3 3,7	1,89	6,66	220	11,6	6,08	82,3	94,3
	6,36	24,8	1,9 4,1	1,78	6,13	211	11,4	5,45	81,6	94,6
	5,42	30,1	2,4 3,6	1,83	5,81	215	11,3	4,77	79,8	95,2
45	7,01	20,2	2,5 3,8	1,92	6,84	243	12,6	6,37	79,6	96,5
	6,17	25,3	2,2 4,2	1,83	6,45	241	12,8	5,85	78,9	96,8
	5,14	29,6	2,7 4,5	1,87	5,98	234	12,5	5,32	78,3	95,9

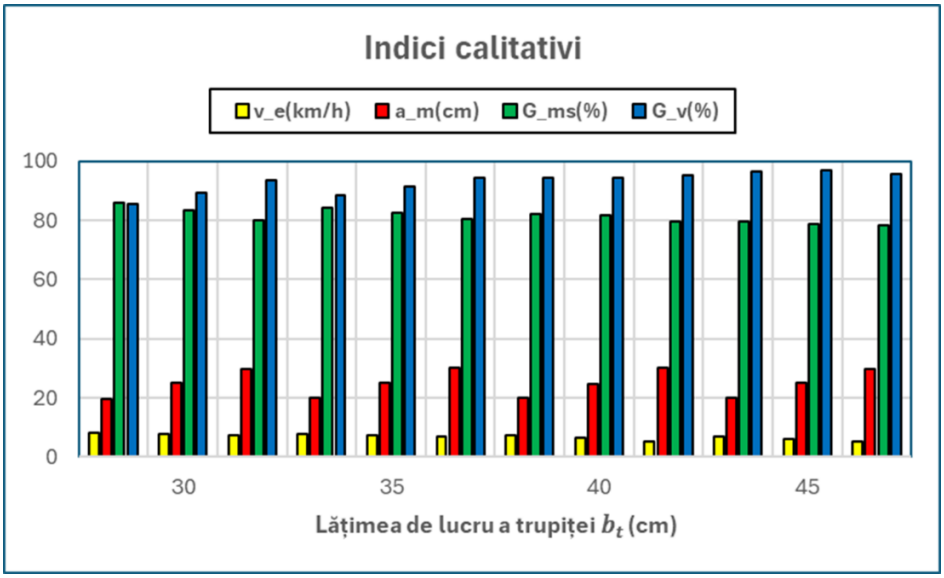


Figura 5.6. *Qualitative indicators of plowing performed with the aggregate consisting of the A 1800-A tractor and PP5VM plow on reddish-brown soil with an average moisture content of 18% in the plowing layer*

Table 5.2. *Energy indices of the aggregate consisting of the A-1800A tractor and the PP5VM plow on reddish-brown soil with an average moisture content of 18% in the plowed layer*

Lățimea de lucru pe trupiță b_t(cm)	Indicii regimului de lucru			Indicii caracteristici pentru aderență, dinamică și energetici			Indicii de productivitate si consum	
	Adâncimea medie de lucru a_m(cm)	Lățimea medie de lucru B_m(cm)	Treapta de viteză	Patinarea medie δ(%)	Viteza de lucru efectivă V_e(Km/h)	Consumul orar de conbustibil q (l/h)	Capacitatea de lucru la timpul efectiv W_{ef}(ha/h)	Consumul specific de combustibil Q(l/ha)
30	19,7	156	VI	11,8	8,04	29,53	1,254	23,54
	25,1	154	V	11,7	7,85	29,57	1,209	24,45
	29,7	153	V	12,1	7,38	30,15	1,129	26,70
35	20,1	186	V	11,9	7,87	29,85	1,464	20,39
	24,9	182	V	12,2	7,45	31,18	1,356	22,99
	30,2	181	IV	12,3	6,83	31,79	1,236	25,72
40	19,9	220	V	12,8	7,42	30,12	1,632	18,45
	24,8	211	IV	13,1	6,36	31,97	1,342	23,82
	30,1	215	III	13,5	5,42	32,11	1,165	27,56
45	20,2	243	V	13,9	7,01	32,25	1,703	18,93
	25,3	241	IV	14,3	6,17	33,75	1,487	22,69
	29,6	234	III	15,5	5,14	34,55	1,203	28,72

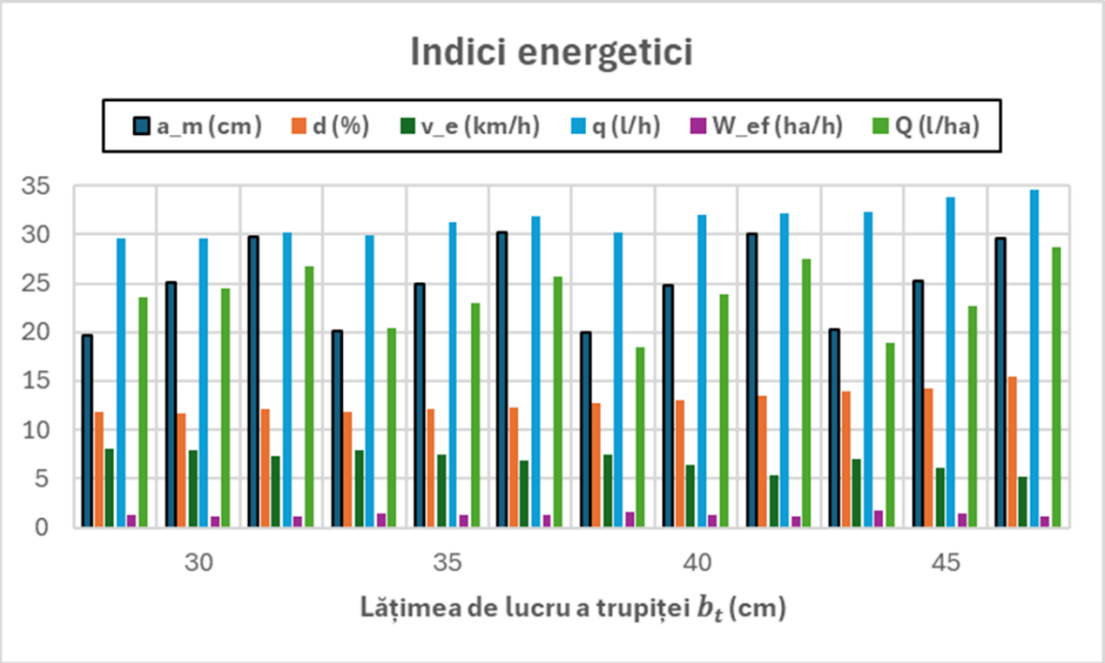


Figura 5.7. *Energy indices of plowing performed with the aggregate consisting of the A 1800-A tractor and PP5VM plow on reddish-brown soil with an average moisture content of 18% in the plowing layer*

During the tests under operating conditions, the operating indices were determined by timing or calculated according to the plow testing procedure developed by INMA Bucharest (INMA-DI 2008). The average values of the productivity and fuel consumption indices determined during tests under production conditions are presented in Table 5.2. Analysis of the data in Table 5.2 shows that the PP5VM plow achieves appropriate productivity and fuel consumption indices. The average values of the working time utilization coefficients (the working width per plow was set at 40 cm and the working depth at 30 cm) are presented in Table 5.3.

Table 5.3. *Operating indices of the aggregate consisting of the A 1800A tractor and PP5VM plow when plowing at a depth of 30 cm and a width of 40 cm on reddish-brown soil with an average moisture content of 18% in the plowed layer*

Index name	**Symbol**	**UM**	**Value**
Operating time utilization coefficient	K_{02}	-	0,939
Total operating time utilization coefficient	K_{03}	-	0,890
Production time utilization coefficient	K_{04}	-	0,866
Shift time utilization coefficient	K_{07}	-	0,731

Return coefficient	K_{21}	-	0,942
Technological safety coefficient	K_{41}	-	0,993
Technical safety coefficient	K_4	-	0,970
Hourly working capacity during effective time	W_{ef}	ha/h	1,165
Hourly working capacity during operating time	W_{02}	ha/h	1,094
Hourly working capacity during total operating time	W_{03}	ha/h	1,037
Hourly working capacity during production time	W_{04}	ha/h	1,009
Hourly working capacity during shift time	W_{07}	ha/h	0,851
Working capacity per 8-hour shift	W_{sch}	ha/sch	6,813
Specific fuel consumption	Q	l/ha	27,56

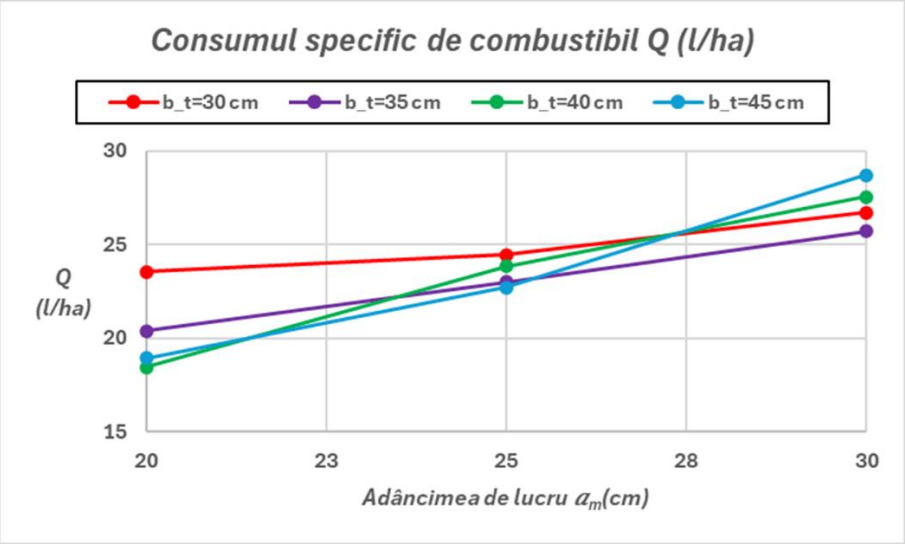


Figure 5.8. *Specific fuel consumption for plowing with the combination of the A 1800A tractor and PP5VM plow on reddish-brown soil with an average moisture content of 18% in the plow layer*

An analysis of the data in Table 5.3 shows that the PP5VM plow achieves appropriate working time utilization coefficients. The PP5VM plow has appropriate operational reliability, with an operational safety coefficient of 0.97. Under normal conditions of soil coverage with evenly distributed plant debris, no clogging of the active parts was reported..

Table 5.4. *Comparison between the energy indices calculated using the algorithms in subsection 4.3.2 and those resulting from field tests of the aggregate consisting of the A-1800 tractor and the PP5VM plow during plowing work.*

Lățimea de lucru pe trupiță b_t (cm)	Indicii regimului de lucru				Indicii energetici caracteristici				Indicii de productivitate și consum			
	Adâncimea teoretică de lucru a_t (cm)	Adâncimea medie reală de lucru a_{mr} (cm)	Lățimea teoretică de lucru B_t (cm)	Lățimea medie reală de lucru B_{mr} (cm)	Viteza de lucru teoretică v_t (km/h)	Viteza de lucru efectivă v_e (km/h)	Consumul orar teoretic de combustibil q_t (l/h)	Consumul orar real de combustibil q_r (l/h)	Capacitatea de lucru teoretică W_t (ha/h)	Capacitatea de lucru reală W_r (ha/h)	Consumul specific teoretic de combustibil Q_t (l/ha)	Consumul specific real de combustibil Q_r (l/ha)
30	20	19.7	150	156	7.2	8.04	28	29.53	1.25	1.254	22.5	23.54
	25	25.1		154		7.85	29	29.57	1.22	1.209	24	24.45
	30	29.7		153		7.38	30	30.15	1.14	1.129	26	26.70
35	20	20.1	175	186		7.87	30	29.85	1.5	1.464	20	20.39
	25	24.9		182		7.45	31	31.18	1.4	1.356	22.5	22.99
	30	30.2		181		6.83	32	31.79	1.3	1.236	25	25.72
40	20	19.9	200	220		7.42	31	30.12	1.6	1.632	18	18.45
	25	24.8		211		6.36	32	31.97	1.4	1.342	23.2	23.82
	30	30.1		215		5.42	33	32.11	1.2	1.165	27.1	27.56
45	20	20.2	225	243		7.01	32	32.25	1.8	1.703	18.3	18.93
	25	25.3		241		6.17	33	33.75	1.5	1.487	21.9	22.69
	30	29.6		234		5.14	34	34.55	1.3	1.203	28.2	28.72

Table 5.4 presents a comparison between the energy indices calculated using the calculation algorithms developed in subsection 4.3.2 and those resulting from experimental field tests for the agricultural aggregate consisting of the A-1800 tractor and the PP5VM plow during plowing. It can be seen that the differences between the calculated values and those resulting from experimental tests, for each index separately, fall within the range of 3-12%, from which it can be concluded that the numerical calculation algorithms developed in subsection 4.3.2 can be validated.

5.6. Experimental research on determining the optimal working process of disc harrows

In March-April 2022, experimental field trials were conducted in Mozăceni, Argeș County, for the working process performed by two types of harrows, one classic -towed GD-3.2 (Figures 5.9, 5.10) and a mounted one, coupled to the GD-3.2P three-point coupling mechanism (Figure 5.11) in combination with a 65 HP U-650 tractor, equipped with a hydraulic lift with automatic traction force control.



Figure 5.9. *Agricultural unit consisting of a U-650 tractor and a GD-3.2 towed disc harrow*



Figure 5.10. *GD-3.2 towed disc harrow*



Figure 5.11. *GD-3.2P mounted disc harrow*

Compared to the classic GD-3.2 trailed disc harrow (Figure 5.10), the GD-3.2P mounted harrow (Figure 5.11) offers a number of advantages, including a productivity increase of over 20% and a reduction in fuel consumption per hectare of over 10%.

The unit consisting of the U-650 tractor and the GD 3.2P mounted disc harrow has longitudinal stability in the transport position, ensured at the limit. At the beginning of the experiments, it was observed that on reddish-brown forest soils, the effect of the GD-3.2P mounted disc harrow on clod size reduction is lower than that of the GD-3.2 trailed disc harrow. This can be explained by the difference in weight between the two harrows.

The disc harrow was ballasted with two additional weights of 105 kg, increasing the total weight of the GD-3.2P harrow from 760 kg to 970 kg. Under such conditions, however, longitudinal stability is no longer ensured, which requires ballasting the front axle of the tractor with additional weights. Based on the above observations, the mounted disc harrow was tested in two variants, namely:

- GD-3.2P - disc harrow carried in its original construction;

- GD-3.2PL - disc harrow carried with additional weights.

Both variants were tested in comparison with the GD-3.2 disc harrow on autumn plowing in reddish brown forest soil, during disc harrowing I and disc harrowing II (two successive disc

harrowings). The mounted harrow variants were tested using both force control (FC) and floating (F) hydraulic systems. In all variants tested, the disc batteries were fixed at a medium tilt position, i.e., 15°. The experimental results obtained are presented below:

Table 5.5. *Experimental results for tensile strength*

The rake variant	Hydraulic lift position	Harrowing	*a* [cm]	B_l [m]	Tensile strenght R_t [N]	Specific strenght [N/m]	[kPa]
GD-3.2	-	I	9-11	3.1	8750	2800	28
	-	II	12-14	3.1	7500	2420	18
GD-3.2P	Floating	I	7-9	3.1	6750	2180	27
		II	9-11	3.1	5500	1800	18
	Effort control	I	6-8	3.1	6000	1900	27
		II	8-10	3.1	5000	1600	17
GD-3.2PL	Floating	I	10-12	3.1	9000	2900	26
		II	13-15	3.1	7500	2410	17
	Effort control	I	8-10	3.1	7750	2500	27
		II	12-14	3.1	6500	2090	16

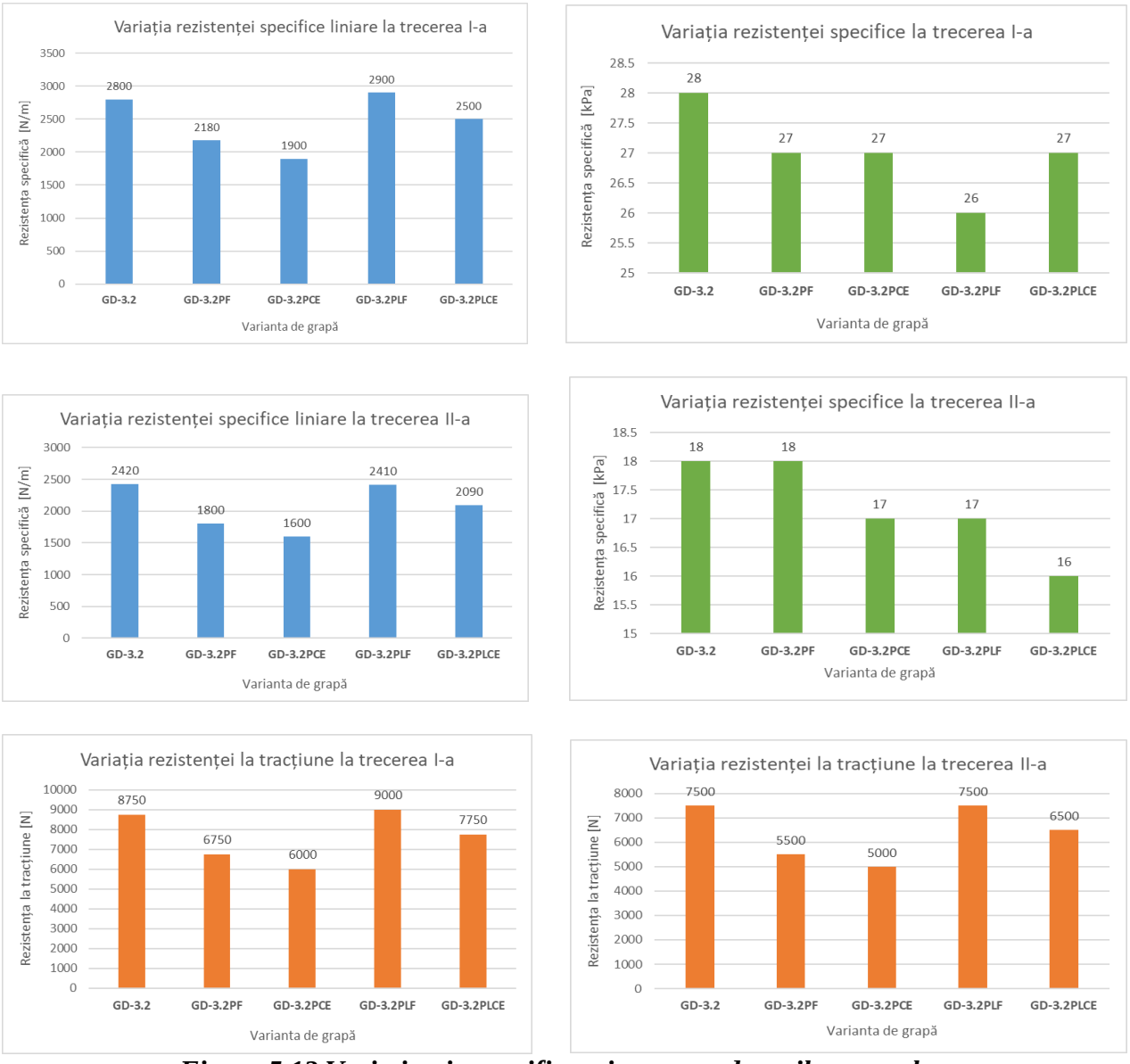
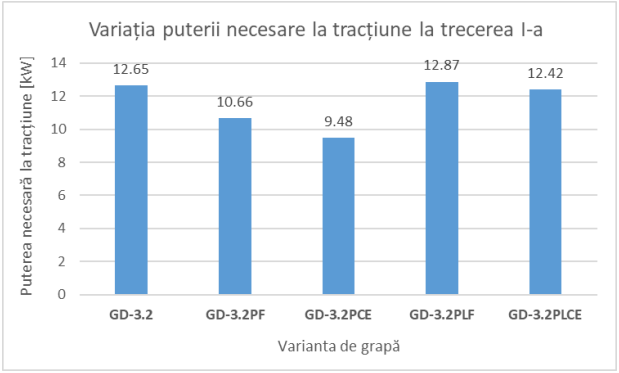
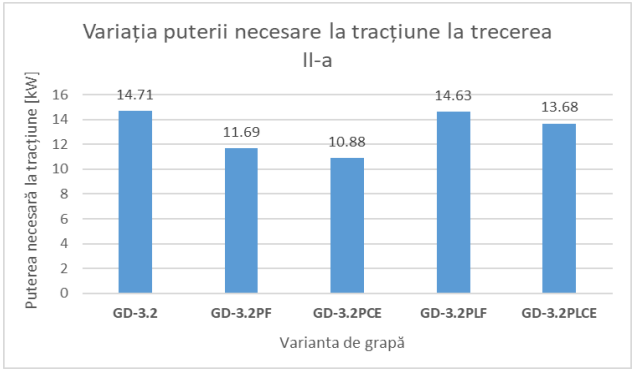


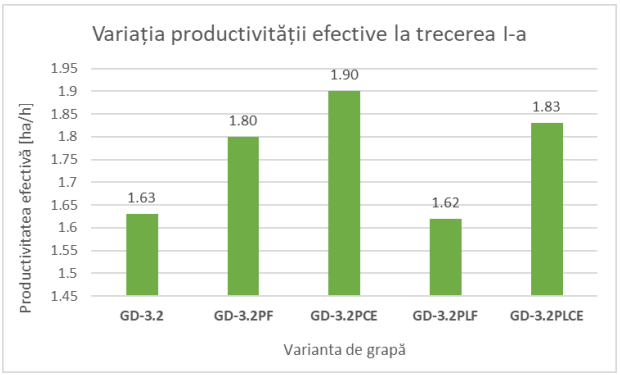
Figure 5.12 Variation in specific resistance and tensile strength for different disc harrow variants at passes I and II

Table 5.6. *Experimental results for tensile strength*

The rake variant	Hydraulic lift position	Harrowing	Working speed gear [km/h]	Skating [%]	R_t [N]	P_t [kW]
GD-3.2	-	I II R	5.28	20	8750	12.65
		II III R	7.20	11	7500	14.71
GD-3.2 P	Floating	I II R	5.80	16	6750	10.66
		II III R	7.80	9	5500	11.69
	Effort control	I II R	6.10	10	6000	9.48
		II III R	8.00	7.5	5000	10.88
GD-3.2 PL		I II R	5.25	15	9000	12.87
		II III R	7.15	12	7500	14.63
	Floating	I II R	5.90	10	7750	12.42
		II III R	7.75	9	6500	13.68







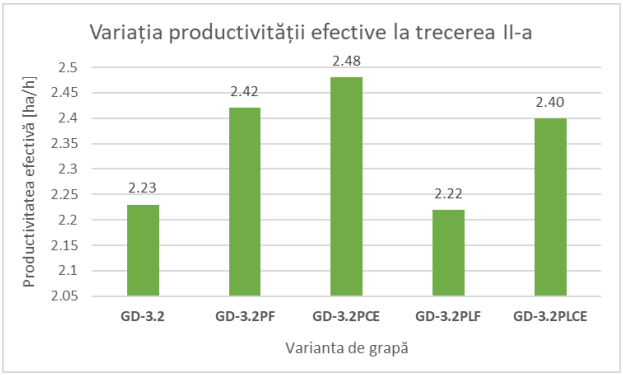


Figure 5.13 Variation in traction power requirements and effective productivity for different disc harrow variants at passes I and II

It can be observed that productivity is higher on the effort control (EC) position than on the floating (F) position in both variants of the mounted harrow, the increase being more significant in the ballasted (L) variant when the traction demand is higher. The increase in productivity is due to reduced slippage, particularly as a result of the increased load on the drive wheels achieved by the hydraulic effort control mechanism, as theoretically shown in subsection 4.3.4.

Energy consumption is lower when the mounted harrows work on effort control (EC) in the GD-3.2PL ballasted version. Under similar depth conditions, the specific energy is 13-14% lower than in the GD-3.2 towed version, due to the reduction in the power required for drive and the increase in working capacity (effective productivity).

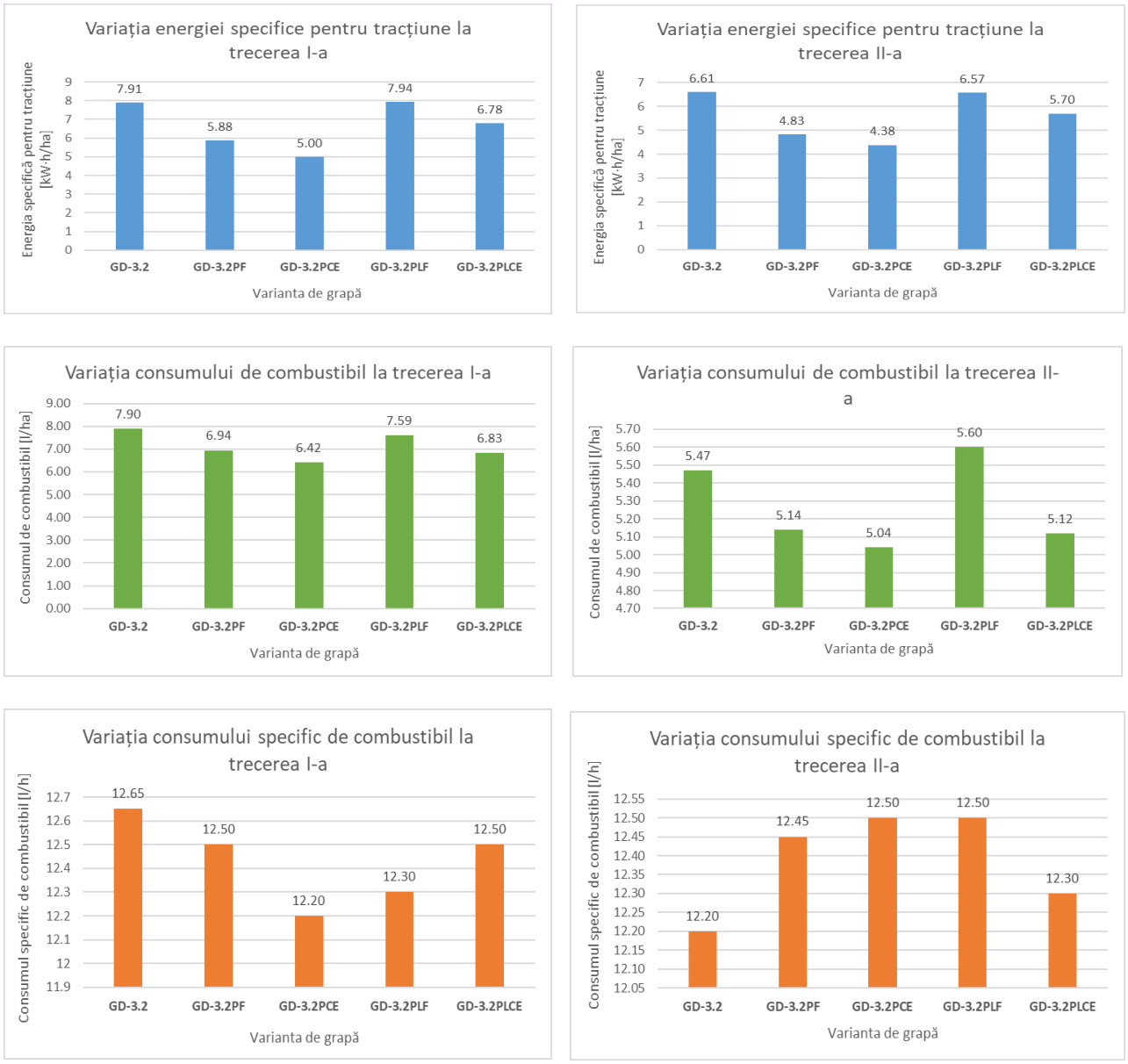


Figure 5.14. Specific traction energy and fuel consumption for different disc harrows (passes I and II)

As a result of increased productivity and reduced power requirements, the hydraulic system with effort control leads to a reduction in fuel consumption per hectare of 6-14% for the mounted and ballasted harrow variant, working with effort control, compared to the trailed harrow variant. The same observation applies to the influence of the effort-controlled lift, namely that efficiency is higher under higher load conditions with the GD-3.2P harrow, where fuel consumption is reduced by 3-7% compared to the floating version of the GD-3.2L (ballasted), and the reduction in fuel consumption compared to the traditional GD-3.2P trailed harrow is 9-10%.

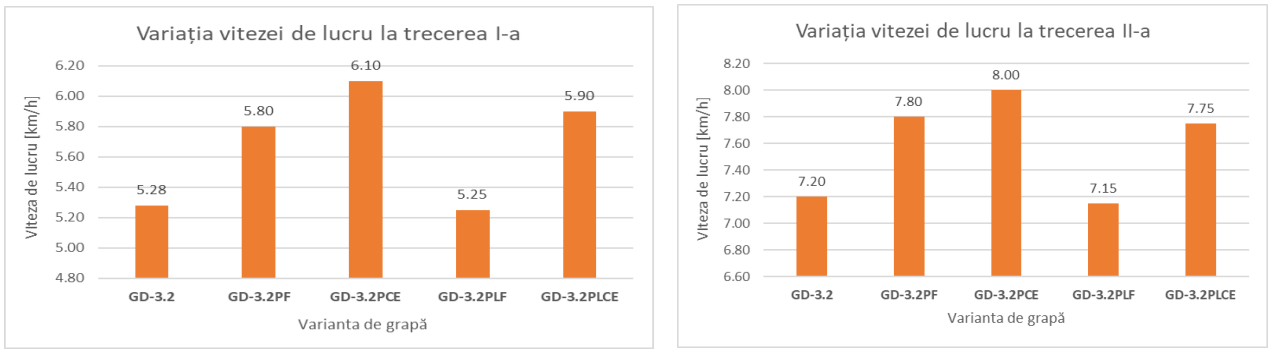


Figure 5.15. Working speed variation of disc harrows at passes I and II

The effect of breaking up clods for the three harrow variants was highlighted by measuring the average sizes of clods exceeding 50 mm, which were determined initially and then after each pass of the harrows, and by distributing them into size groups. As can be seen, the GD-3.2P disc harrow, in its initial construction, has a lower crushing effect than the GD-3.2 trailed disc harrow. After ballasting, the effect improved, with better crushing than the GD-3.2, which can be attributed to the notched front discs.

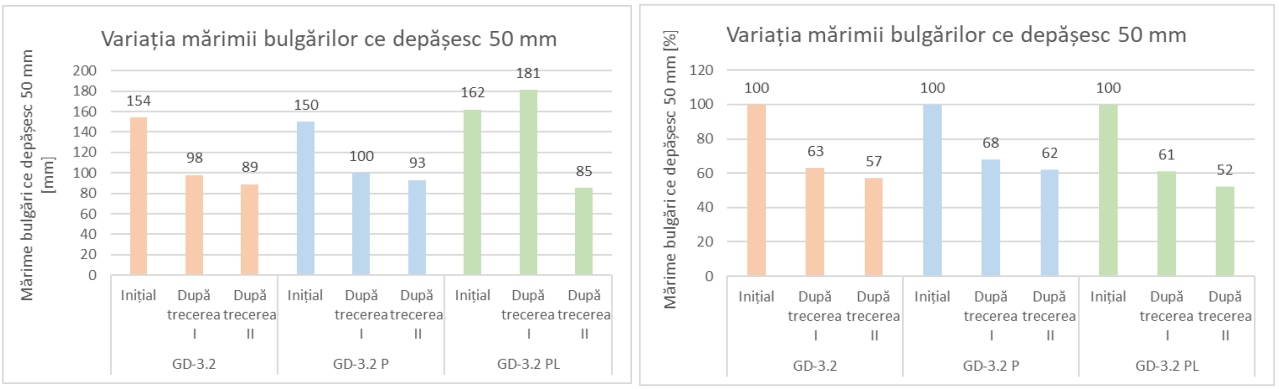


Figure 5.16. *Variation in the size of soil clods exceeding 50 mm*



Figure 5.1.7. Soil clod size distribution for different disc harrows across successive passes

Finally, it appears that the GD-3.2P disc harrow must be ballasted in order to achieve working quality indices comparable to those achieved with the GD-3.2 disc harrow. The ballasted GD-3.2P disc harrow can work in combination with the U-650 tractor with additional weights on the front axle and the hydraulic lift lever in the "floating" position, in which case the operating indices are practically equal to those of the U-650+GD-3.2 combination. When used in combination with a tractor equipped with a hydraulic lift with effort control, productivity is increased and fuel consumption per hectare is reduced by more than 5%.

Table 5.7. *Comparison between the energy indices calculated using the algorithms in subsection 4.3.4 and those resulting from experimental field tests for the aggregate consisting of the U-650 tractor and the GD-3.2 and GD-3.2P disc harrows during disc harrowing work.*

Rake variant	Hydraulic lift position	Passing	Theoretical working speed (km/h)	Actual working speed (km/h)	Theoretical tensile strength (N)	Actual tensile strength R_{tr} (N)	Theoretical power requirement P_{tt} (kW)	Actual power requirement P_{tr} (kW)
GD-3.2		I	6	5.28	8300	8750	13	12.65
		II	7.2	7.20	7200	7500	13.8	14.71
GD-3.2 P	Floating	I	6	5.80	7100	6750	11.3	10.66
		II	7.2	7.80	6000	5500	11.6	11.69
	Effort control	I	6	6.10	6300	6000	9.1	9.48
		II	7.2	8.00	5100	5000	10.3	10.88

Table 5.7. presents a comparison between the energy indices calculated using the calculation algorithms developed in subsection 4.3.4 and those resulting from field experiments for the agricultural aggregate consisting of the U-650 tractor and the GD-3. 2, respectively the GD-3.2P mounted disc harrow for disc harrowing. It is found that the differences between the calculated values and those resulting from experimental tests, for each index separately, fall within the range of 5-10%, from which it follows that the numerical calculation algorithms developed in subsection 4.3.4 can be validated.

Chapter 6 CONCLUSIONS. PERSONAL CONTRIBUTIONS. PERSPECTIVES

6.1. Conclusions

- Agricultural machinery used to prepare the seedbed for planting crops is among the largest consumers of fuel on the farm, which requires their optimal operation: the best possible quality indicators, minimum energy consumption, and high productivity.
- Optimal operating performance can be achieved through experimental research that generates empirical models and through mathematical modeling of the interdependencies between process factors (soil, working body, speed, depth, compaction), models that can be solved numerically with the development of computers.
- Currently, including from the perspective of using autonomous vehicles for agriculture, algorithms are needed (which are still lacking in most cases) to determine the optimal working regime of tractor-machine aggregates (e.g., minimizing specific consumption while maintaining seedbed quality), serving as a basis for automatic decisions on operating parameters.
- Studies and research show that in order to develop calculation algorithms for determining the optimal working regime of agricultural seedbed preparation machines, it is necessary to know the physical -mechanical properties of the processed soil and their variation depending on various factors, as well as detailed knowledge of the working process of these machines.
- Agricultural machinery used for seedbed preparation can have both negative and positive effects on the physical and mechanical properties of the soil, which is why it must be selected with care.
- The optimization criteria considered for seedbed preparation machines are: maximum working capacity of the aggregates, minimum energy consumption per unit of work performed, minimum fuel consumption per unit of work performed, minimum power of the aggregate's energy source, low weight of the aggregates, low labor requirements, minimum material consumption per unit of work performed, superior quality indicators, maximum reliability of the aggregates, minimum service life of the machines, maximum comfort conditions, minimum expenses per unit of work performed, maximum efficiency, etc.
- To optimize the seedbed preparation process, it is necessary to develop mathematical models that simulate the energy consumption of the components of the agricultural machinery system.
- The tensile strength of agricultural seedbed preparation machines, like other parameters of the aggregate, has a pronounced random character. A number of factors influence the variation

characteristics, the most important of which are: soil type, soil compaction, moisture, unevenness, texture, and structure of the tilled soil, as well as some variations that occur at the drive wheels and articulation points of the aggregate.

- The variation in the working resistance of agricultural seedbed preparation machines leads to unstable operation of the tractor engine. Depending on this variation and the engine load coefficient, power losses of up to 10-15% occur.
- It is necessary to determine the optimal operating parameters for agricultural aggregates intended for seedbed preparation, which ensure the full use of the tractor engine power and the use of the aggregate at maximum working capacity, respectively, achieving an optimal power balance. Currently, this can be achieved using analytical and numerical calculation algorithms that can be implemented on modern agricultural tractors.
- Agricultural aggregates, under real working conditions, are used in the presence of influencing factors with a pronounced random character.
- In the case of stationary processes, the statistical characteristics of the analyzed parameters are obtained by examining and successively calculating the measurable functions, thus resulting in the statistical characteristics of the entire process.
- In the analysis of the working process specific to a mobile agricultural aggregate for seedbed preparation, both the influences of the micro-relief acting on the aggregate, manifested by the variation in the power required for movement, and the influences of the heterogeneity of the processed material, evidenced by the variation in the power required by the working parts, are of interest.
- The indicators for the operation of the agricultural system for seedbed preparation reflect the efficiency of its operation.
- The tensile strength of the plow increases as its speed increases, being lower at low speeds (0.5-2 m/s) and much higher at higher working speeds (2-3.5 m/s).
- Optimal use of plowing equipment is essential for efficient resource utilization and cost reduction.
- Using the full power of the tractor engine and operating the plowing unit at maximum working capacity allows for optimal power balance. The optimal operating mode can be determined using numerical calculation algorithms based on Lagrange multipliers, with the help of calculation programs. To achieve maximum productivity at the engine power level, it is necessary to calculate the optimal working speed and working width, depending on the coefficient of utilization of the plowing unit's travel time.
- As the working depth increases, the specific mechanical work required for soil cultivation using the leveler decreases. Adjusting the cutting angle of the blade to values close to 90° contributes to reducing the specific mechanical work of the operation, as the use of the leveler is more efficient at greater depths.
- For the same working conditions, the traction force of the U-650 tractor increases considerably if the disc harrow is coupled to the tractor in the mounted version because the reaction value on the drive axle increases compared to the semi-mounted coupling version, significantly increasing the driving force.

6.2. Personal contributions

- ✓ Analysis of the state of global research on seedbed preparation
- ✓ Analysis of methods for optimizing technical systems and development of a library of programs for numerical calculation.
- ✓ Development of a theoretical study on mathematical modeling of the energy consumption of plows.
- ✓ Development of a Python software package for mathematical modeling of the optimal operation of plowing aggregates.
- ✓ Conducting experimental research to determine the optimal operating regime of plowing aggregates and validate mathematical models.

- ✓ Developing a theoretical study on the mathematical modeling of the energy consumption of semi-mounted and mounted disc harrows..
- ✓ Developing a Python software package for the mathematical modeling of the optimal use of tractor-mounted semi-mounted and mounted disc harrows.
- ✓ Conducting experimental research to determine the optimal working process of aggregates formed by tractors with semi-mounted and mounted disc harrows and validating mathematical models.
- ✓ Capitalizing on the results of the studies and research carried out in the doctoral thesis by developing and publishing a number of 8 scientific papers in specialized journals or in volumes of national and international conferences as author and co-author (including one in an ISI-indexed specialized journal and one in a SCOPUS-indexed specialized journal)

6.3. Perspectives

- ✓ This doctoral thesis provides a solid basis for further research aimed at developing the theory of optimal use of agricultural aggregates for seedbed preparation, improving mathematical models, and developing calculation algorithms applicable to all agricultural soil cultivation machines.
- ✓ In view of the imminent transition to the use of autonomous agricultural aggregates for seedbed preparation, the applicability of such algorithms in generating assisted decisions for real-time adjustment of the operating parameters of agricultural aggregates is envisaged
- ✓ Taking into account the fact that agricultural aggregates for seedbed preparation, under real working conditions, are used in the presence of influencing factors with a pronounced random character, it is expected that mathematical models and numerical calculation algorithms will be developed that will allow the abstraction, with the help of random process theory, of the working regime for these agricultural aggregates in order to optimize their operation.

Selective bibliography

AboAl-Kheer, A., M.G. Kharmanda, A. El Hami, și A.M. Mouazen. 2011. „Estimating the variability of tillage forces on a chisel plough shank by modeling the variability of tillage system parameters.” *Computers and Electronics in Agriculture* (1): 61-70.

Ahmadi, I. 2017. „A power estimator for an integrated active-passive tillage machine using the laws of classical mechanics.” *Soil and Tillage Research, Vol. 171* 1-8.

Ancău, M., și L. Nistor. 1996. *Tehnici numerice de optimizare în proiectarea asistată de calculator.* Bucureşti: Editura Tehnică.

Ani, O. A., B. B. Uzoejinwa, A. O. Ezeama, A. P. Onwualu, S. N. Ugwu, și C. J. Ohagwu. 2018. „Overview of soil-machine interaction studies in soil bins.” *Soil and Tillage Research* 175: 13-27.

Anpat, R.M., și H. Raheman. 2017. „Investigations on power requirement of active-passive combination tillage implement.” *Engineering in Agriculture. Environ. Food* 10: 4-13.

Babiciu, P., și S.ȘT. Biriș. 2000. „Interdependenţa factorilor de influenţă a procesului de arat.” *Construcţia de maşini* 1-2: 35-37.

Balsari, P., Biglia, A., Comba, L., Sacco, D., Eloi Alcatrão, L., Varani, M., Mattetti, M., Barge, P., Tortia, C., Manzone, M., Gay, P., Ricauda Aimonino, D. 2021. „Performance analysis of a tractor - power harrow system under different working conditions.” *Biosystems Engineering* 28-41.

Bebea, N. 1978. *Metode pentru rezolvarea problemelor de optimizare.* Bucureşti: Editura Didactică şi Pedagogică.

Biriş, S. Şt., N. Ungureanu, N. E. Gheorghiță, E. Maican, și V. Vlăduț. 2017. „Theoretical research on enhancing the performance of cultivators working bodies.” *Proceedings of the 45th International Symposium on Agricultural Engineering "Actual Tasks on Agricultural Engineering"* . Opatija / Croatia. 121-130.

Brătucu, GH. 2010. „Mathematical Model of the Energetic Consumption for Digging Soil Machines in Greenhouses.” *Bulletin of the Transilvania University of Braşov* 3 (52): 143-150.

Canarache, Andrei. 1990. *Fizica solurilor agricole.* Bucharest: Editura CERES.

Căproiu Şt., et al. 1982. „Agricultural machinery for soil tillage, seeding and crop maintenance.” (Didactic and Pedagogic Publishing House).

Cârlan, M. 1994. *Probleme de optimum în ingineria sistemelor tehnice.* Bucureşti: Editura Academiei Române.

CIGR Handbook of Agricultural Engineering, Plant Production Engineering. 1999. Vol. III. American Society of Agricultural Engineers.

Ciulu, GH., și GH. Bârcă. 2002. *Optimizarea exploatării agregatelor agricole.* Vol. II. Craiova: Reprografia Universităţii din Craiova.

Constantinescu, A., Gh. Popa, și I. Dumitru. 2006. „The energetic analyse of the system tractor-agriculture machine used for the preparation of the soil for sowing." *The 1st International Conference on Motor Vehicle and Transportation MVT 2006.* Timisoara, Romania.

Constantinescu, A., și S. Popescu. 2009. „Equipment and methodology for experimental research of the dynamic and energetic of the high power agricultural tractors of in aggregate with tillage machine systems." *The 3rd International Conference "Computational Mechanics And Virtual Engineering And Applications In Automotive Engineering", COMEC 2009.* Braşov: Universitatea Transilvania din Braşov.

Dobrescu, C. 1981. *Optimizarea parametrilor agregatelor agricole în scopul reducerii consumurilor.* Bucureşti: Centrul de material didactic şi propagandă agricolă.

Gheorghiță, N.E., S.Șt. Biriș, N.V. Vlăduț, N. Ungureanu, E. Maican, și M. Matache. 2022. „Research on the development of a calculus algorithm to estimate the resistant force of self-vibrating cultivators used for seedbed preparation." *U.P.B. Sci. Bull., Series D* 84 (2): 185-195.

Gheres, M., și V. Roș. 2007. „Mathematical model for soil tillage energy evaluation." *Simpozion Tehnologii de mecanizare şi echipamente tehnice pentru agricultură şi industria alimentară armonizată la practica U.E., INMATEH 2007-III.* Bucureşti, România. 213-219.

Gherеș, M.I. 2014. „Mathematical model for studying the influence of tillage tool geometry on energy consumption." *INMATEH -Agricultural Engineering* 42 (1): 5-12.

Gill, W.R., și G.E. Vanden Berg. 1968. *Soil dynamics in tillage and traction.* USA, Washington D.C: U.S.A. Department of Agriculture, Handbook 316.

Keshavarzpour, F. 2012. „Response of some important physical and mechanical properties of soil to different tillage methods." *American-Eurasian Journal of Agricultural and Environmental Sci.* 12 (7): 914-916.

Koolen, A.J., și H. Kuipers. 1983. *Agricultural soil mechanics.* Vol. 13. Springer, Heidelberg: Advanced Series in Agricultural Sciences.

Kumar, A., Shrivastava, A.K., Nandini, Y., Namdeo, R. 2023. „Performance evaluation of trailed type disc harrow on vertisols field condition." *International Journal of Statistics and Applied Mathematics, SP-8(6)* 329-333.

Legay, I. M. 1988. *Methodes et models dans l'etude des sistemes complexes. Pour une agriculture divesifieé.* Paris: Ed. L'Harmattan.

Lonkwic, P., Usydus, I., Tofil, A., Krakowski, T., Ruta, H., Pieniak, D. 2021. „Case Study on Numerical Calculation of a Disc Bush in the Disc Harrow in the Welding Version." *Mechanika* 513-520.

M. Rashidi, M., Lehmali, H.F., Beni, M.S., Malekshahi, M., Tabrizi Namin, S. 2013. „Prediction of Disc Harrow Draft Force Based on Soil Moisture Content, Tillage Depth and Forward Speed." *Middle-East Journal of Scientific Research, Vol. 15, Iss. 2* 260-265.

Mattetti, M., M. Varani, G. Molari, și F. Morelli. 2017. „Influence of the speed on soil-pressure over a plough." *Biosystems Engineering* 156: 136-147.

McKyes, E. 1985. *Soil cutting and tillage.* Elsevier: Amsterdam-Oxford-New York-Tokyo.

Md-Tahir, H., J. Zhang, J. Xia, Y. Zhou, H. Zhou, J. Du, și H. Mamona. 2021. „Experimental investigation of traction power transfer indices of farm-tractors for efficient energy utilization in soil tillage and cultivation operations.” *Agronomy* 11 (1): 168.

Meca, V.A., P. Cârdei, și G. Konstandinov. 2012. „Studies and research for unifying the resistance expression of machines designed to soil tillage with applications in their working regime optimization.” *INMATEH -Agricultural Engineering* 36 (1).

Moise, V., S.Șt. Biriș, B. Grecu, N. Ungureanu, L. David, și G. Paraschiv. 2010. *Determination of the minimum surface of an agricultural farm from which a certain power range of tractors become profitable.* Vol. 38. Opatija, Croatia: Symposium ”Actual Tasks on Agricultural Engineering”.

Năstăsoiu, S., Andreescu, C., Popescu, S., Frățilă, Gh., Cristea, D. 1983. *Tractoare și automobile.* București: Editura Didactică și Pedagogică.

Okoko, P., Ajav, E.A., Olosunde, W.A. 2018. „Draft and power requirements for some tillage implements operating in clay loam soil.” *Agricultural Engineering International: CIGR Journal, Vol. 20, No. 1* 95-102.

Perdok, U. D., și J. K. Kouwenhoven. 1994. „Soil-tool interactions and field performance of implements.” *Soil and Tillage Research* 30: 283-326.

Roș, V., ș.a. 1998. *Model matematic pentru analiza energetică a procesului de prelucrare a solului.* Cluj-Napoca: Conferinţa TRANSAGRATECH.

Șandru, A. ș.a. 1983. *Exploatarea utilajelor agricole.* Bucureşti: Editura Didactică şi Pedagogică.

Scripnic, V., și P. Babiciu. 1979. *Maşini agricole.* Bucureşti: Editura Ceres.

Simionescu, I., M. Dranga, și V. Moise. 1995. *Metode numerice în tehnică.* Bucureşti: Editura Tehnică.

Srivastava, A. K., E. G. Carroll, P. R. Roger, și R. B. Dennis. 2006. „Soil Tillage.” *Engineering Principles of Agricultural Machines* 169-230.

Tecușan, N., Ionescu, E. 1982. *Tractoare și automobile.* București: Editura Didactică și Pedagogică.

Teșu, T., ș.a. 1984. *Energia şi agricultura.* Bucureşti: Editura Ceres.

Trendafilov, K., G. Tihanov, V. Stoykova, și G. Shivacheva. 2023. „ALGORITHM FOR OPTIMIZING THE MOVEMENT OF A MOUNTED MACHINE-TRACTOR UNIT IN THE HEADLAND OF AN IRREGULARLY SHAPED FIELD.” *INMATEH-Agricultural Engineering.*

Trevini, M., Tosti, G., Benincasa, P. 2024. „Agronomic performance of disc chain harrow as a conservation agriculture tool for a one-step cover crop termination and seedbed preparation.” *Experimental Agriculture, Vol. 60* 1-11.

Upadhyay, G., și H. Raheman. 2020. „Effect of velocity ratio on performance characteristics of an active-passive combination tillage implement.” *Biosystems Engineering* 191: 1-12.

Varani, M., M. Mattetti, G. Molari, A. Biglia, și L. Comba. 2023. „Correlation between power harrow energy demand and tilled soil aggregate dimensions.” *Biosystems Engineering* 225: 54-68.

Vlad, C. 2013. *Cercetări privind optimizarea energetică a procesului de pregătire a patului germinativ la înfiinţarea culturilor de legume - Teza de doctorat.* Brașov: Universitatea Transilvania din Braşov.

Vlăduț, D.I., S-Șt. Biriș, V. Vlăduț, D. Cujbescu, N. Ungureanu, și Găgeanu I. 2018. „Experimental researches on the working process of a seedbed preparation equipment for heavy soils." *INMATEH - Agricultural Engineering* 55: 27-34.

LIST OF PAPERS

1. Biriș S.Șt., **Lacatusu C-tin.**, Moise V., Atanasov A., (**2019**). *A mathematical algorithm for the calculation of the optimum time for using of an agricultural machine*. Proceedings of 6th International Conference „Research People and Actual Tasks on Multidisciplinary Sciences", pp. 295-300, ISSN 1313-7735, Printing House "Angel Kanchev" University of Ruse, 12 – 15 June 2019, Lozenec, Bulgaria (BDI – CABI).
2. S.Șt. Biriș, A.M. Tăbărașu, N.V. Vlăduț, **C-tin Lăcătușu**, (**2022**). *Using the finite element method for structural analysis of lateral tie rods of the suspension mechanism at the tractor*. AGRI INMA -Sustainable Agriculture and Environmental Protection, No. 1/2022, pp. 26-32
3. **Constantin LĂCĂTUȘU**, Adrian IOSIF, Sorin-Ștefan BIRIȘ, Victor MOISE, Nicolae-Valentin VLĂDUȚ, Mihai Gabriel MATACHE, Neluș Evelin GHEORGHIȚĂ, Edmond MAICAN, Iulian HÂNCU, Nicoleta UNGUREANU (**2023**). *CONTRIBUTIONS TO CREATING AN ALGORITHM OF CALCULATION OF OPTIMAL OPERATING PARAMETERS FOR A COMPLEX AGRICULTURAL MACHINE FOR SEEDBED PREPARATION*, AGRI INMA -Sustainable Agriculture and Environmental Protection, Vol. 2. No. 1/2023, pp. 61-68.
4. Alexandru IONESCU, Costin MIRCEA, Dan CUJBESCU, Nicolae-Valentin VLĂDUȚ, Cătălin PERSU, Cătălin LAZĂR, Claudiu UTOIU, **Constantin LĂCĂTUȘU**, Robert BLEJAN, Lazar SAVIN (**2023**). *ADVANCED APPROACHES AND SUSTAINABLE PRACTICES FOR WEED CONTROL*. AGRI INMA -Sustainable Agriculture and Environmental Protection, Vol. 2. No. 1/2023, pp. 10-24.
5. Alexandru IONESCU, Dan CUJBESCU, Costin MIRCEA, Nicolae-Valentin VLĂDUȚ, Cătălin PERSU, Cătălin LAZĂR, Claudiu UTOIU, **Constantin LĂCĂTUȘU**, Robert BLEJAN, Atanas ATANASOV (**2023**). *INVASIVE WEEDS IN AGRICULTURAL ECOSYSTEMS ON CLIMATE CHANGE: IMPACT, MANAGEMENT AND RESTORATION*. AGRI INMA -Sustainable Agriculture and Environmental Protection, Vol. 2. No. 1/2023, pp. 25-42.
6. S.Șt. BIRIȘ, **C-tin LĂCĂTUȘU**, N.V. VLĂDUȚ, N.E. GHEORGHIȚĂ, N. UNGUREANU, E. MAICAN, A. IOSIF, (**2024**). *RESEARCH ON DETERMINING THE PERFORMANCE OF A VARIABLE WIDTH PLOUG DESIGNED FOR HIGH-POWER TRACTORS (180-240 HP)*, Proceedings of XV International Agriculture Symposium "AGROSYM 2024", 10-13 October 2024, pp. 279-285, Bosnia and Herzegovina
7. **C-tin LĂCĂTUȘU**, S.Șt. BIRIȘ, A. IOSIF, N.V. VLĂDUȚ, N.E. GHEORGHIȚĂ, N. E. MAICAN, (**2025**). *RESEARCH ON OPTIMIZING THE POWER BALANCE OF A PLOWING AGGREGATE COMPRISED OF A 180 HP TRACTOR AND A 5-MOLDBOARD PLOW*, INMATEH – Agricultural Engineering, Vol. 75, No. 1 / 2025, pp. 985-994, (Q4 FI=0.7), DOI10.35633/inmateh-75-83, (**WOS:001476008300014**)
8. **Constantin LĂCĂTUȘU**, Sorin-Ștefan BIRIȘ, Nicolae-Valentin VLĂDUȚ, Neluș-Evelin GHORGHIȚĂ, Mariana IONESCU, Nicoleta UNGUREANU, Adrian IOSIF, Edmond

MAICAN, (**2025**). THEORETICAL RESEARCH ON IMPROVING THE PERFORMANCE OF A 65 HP AGRICULTURAL TRACTOR USED FOR HARROWING OPERATIONS, U.P.B. Sci. Bull., Series D, Vol. 4, Iss. 4, 2025, ISSN 1223-7027, pp. ..... (Scopus)